TAMARIX SPECIES (SALT CEDAR) STEM DENSITY
ALONG FLUVIAL AND SALINITY GRADIENTS
ON THE SALT PLAINS NATIONAL
WILDLIFE REFUGE

By

KAREN LOUISE RAY

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Thesis Approved:

William J. Henley

Thesis Adviser

Stephen W. Hallgren

Gail Wilson

A. Gordon Emslie

Dean of the Graduate College

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CHAPTER I

LITERATURE REVIEW

TAMARIX (SALT CEDAR)

Riparian ecosystems are fertile corridors that support high levels of environmental heterogeneity and biological diversity (Birken and Cooper 2006). Along these rivers a variety of trees, shrubs, grasses, and wildflowers have adapted to a dynamically disturbed environment (Anderson and Masters 2007). Riparian ecosystems have numerous functions, but most notably they store water and reduce flooding, stabilize stream banks, improve water quality by collecting sediment and nutrients, stabilize stream temperature by shading, provide shelter and food for aquatic organisms, harvestable forests comprised of native trees, human recreation, and provide grasslands for livestock (Anderson and Masters 2007). Riparian ecosystems are vulnerable to the establishment and spread of exotic species partly due to the relatively high natural disturbance rate and the ability for rapid, long-distance propagule dispersal (Sher et. al 2002). The most documented riparian exotic vascular plant invaders in the United States are *Tamarix chinensis* and *T. ramosissima* (tamarisk, salt cedar) and their hybrids, hereafter referred to as *Tamarix* (Whitcraft et al. 2007). *Tamarix* species form dense monocultures that severely change vegetation composition (Busch and Smith 1995, Baalaman 1965), animal species diversity (McDaniel et al. 2004, Cleverly et al. 1997), soil salinity (Ladenburger et al. 2006, Glenn and Nagler 2005), and hydrology (Stromberg 2001, Graf 1978). *Tamarix* originated in

India and then spread throughout Asia and the Middle East**.** In the early 1800s, *Tamarix* was introduced to North America for soil erosion control (Robinson 1965, McDaniel et al. 2004) and for landscaping purposes (Stromberg et al. 2005). Since its introduction, *Tamarix* has spread approximately 20 km per year, infesting 1.4 million ha as of 2003 (McDaniel et al. 2004, Glenn et al. 2005). *Tamarix* is the dominant vegetation type along many southwestern (Stromberg et al. 2005) and Oklahoma rivers (Anderson and Masters 2007). Although changes in vegetation composition, animal diversity, soil salinity, and hydrology are often due to dense *Tamarix* monocultures (Busch and Smith 1995, Cleverly et al. 1997, Ladenburger et al. 2006), the underlying cause may be river damming and flood suppression (Stromberg 2001).

The primary process determining stream channels, floodplains and floodplain vegetation is a river hydrologic regime (Scott et al. 2004). However, due to extensive river damming and channeling in the 1940s, virtually every major river had its natural flow regime altered. Dams and channels alter the timing, magnitude, and frequency of high and low flows (Magilligan and Nislow 2004). High flows or floods deposit fine moist sediment that serve as ideal substrate for the germination and seedling establishment of *Populus deltoides* (cottonwoods), *Salix nigra* (willows) and *Tamarix* (Scott et al. 2004, Glenn et al. 2005). *Populus deltoides* and *S. nigra* release seeds March through May in association with natural spring peak flows on unaltered rivers, the natural disturbance regime. However, on altered rivers water is released from the dams during water shortages in summer, not in spring. Therefore, reducing the availability of spring water and suitable seedbeds needed for native tree seed germination and seedling establishment. Thus, alterations in frequency of flows actual favor *Tamarix* summer seed release, encouraging its spread while diminishing native tree establishment (Glenn et al. 2005).

These river alterations also restrict water flow and flooding downstream, lowering the water table while increasing soil salinity and drought conditions downstream. The accumulation of soil salts along altered rivers also favor the growth of salt tolerant plant species like *Tamarix*. *Populus deltoides* and *S. nigra* can survive in soil salinities as high as 14.9 mmhos/cm whereas *Tamarix* may tolerate salinities as high as 44 mmhos/cm. Considering elevated soil salinity and limited flooding, riparian habitats may no longer be suited for *P. deltoides* and *S. nigra* (Glenn et al. 2005).

Tamarix, P. deltoids, and S. nigra possess many similar characteristics. These characteristics are: (1) high seed production; (2) rapid germination; (3) high growth rate; (4) high evapotranspiration rates; (5) high leaf index; and (6) flood tolerance (Glenn et al. 2005). However, the native trees possess a greater tolerance to sediment burial than *Tamarix*. Where *Tamarix* posses a greater tolerance to drought, high salt, and fire than natives (Glenn et al. 2005). Some scientists believe *Tamarix* is not highly invasive, but merely a stress tolerant species suited to the alter rivers (Shaforth et al.1995). Management protocol could change dramatically depending on whether *Tamarix* is a highly invasive or stress tolerant species (Glenn et al. 2005). If *Tamarix* were a highly invasive, restoring native habitat would involve *Tamarix* removal. However, if *Tamarix* were a stress tolerant replacement species, restoration management would involve returning the natural flood regime with no *Tamarix* removal necessary (Sher et al. 2002).

Controlling *Tamarix* is a difficult task that has been practiced since the 1940s. It was learned early on no single method is effective. Combined mechanical, chemical, biological and/or burning treatments over an extended period of time are the current methods for reducing *Tamarix* populations, which may or may not be successful (Taylor et al. 2006).

Mechanical control can be implemented as individual plant treatments or on a broad scale. Individual plant treatments include hand pulling, hoeing or digging. This extremely labor-intensive type of control is usually performed on seedlings and young plants. Tractors or excavators are used in broad scale treatments, which are less labor intensive, but costly. Furthermore, all mechanical removal must be followed with a chemical application (McDaniel et al. 2004).

Herbicide control is the most common method and can be applied by fixed-wing aircraft, helicopter, power sprayers, backpack sprayers, and carpet rollers. Herbicides are combined with burning or mechanical treatment. However, with the use of herbicides involves risks of herbicide drift and ground or surface water contaminations.

Biological control involves the release of the saltcedar leaf beetle (*Diorhabda elongata*). The saltcedar leaf beetle defoliates the plant, and can reduce *Tamarix* populations, but will not eradicate it. However, the long-term reduction and mortality of defoliated *Tamarix* is unknown (McDaniel et al. 2004).

Currently these methods are costly, ranging from $750 to $1,300 per ha (McDaniel et al. 2004). However, if an altered flow regime leads to *Tamarix* invasion, then returning the natural flood regime to altered rivers by dam removal or controlled reservoir water release may be the least costly control method.

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CHAPTER II

INTRODUCTION

TAMARIX SPECIES (SALT CEDAR) STEM DENSITY ALONG FLUVIAL AND SALINITY GRADIENTS ON THE SALT PLAINS NATIONAL WILDLIFE REFUGE

Our national parks and refuges were once thought of as protected areas. However, in today's increasingly connected commerce, the native animals and plants of these places are now endangered by the introduction and spread of exotic (non-native) species**.** *Tamarix chinensis* and *T. ramosissima* and their hybrids (*T. ramosissima* / *T. chinensis* with *Tamarix parviflora* /*Tamarix gallica*) are one of these invasive exotics, hereafter referred to as *Tamarix.* Pervious research has determined *Tamarix* species to be a major threat to river ecosystems because of its ability to form dense monocultures that severely change vegetation composition (Busch and Smith 1995, Baalaman 1965), animal species diversity (McDaniel et al. 2004, Cleverly et al. 1997), soil salinity (Ladenburger et al. 2006, Glenn and Nagler 2005), and hydrology (Stromberg 2001, Graf 1978).

Tamarix originated in India and then spread throughout Asia and the Middle East**.** In the early 1800s, *Tamarix* was introduced to North America for soil erosion control (Robinson 1965, McDaniel et al. 2004) and for landscaping purposes (Stromberg et al. 2005). Since its introduction, *Tamarix* has spread approximately 20 km per year, infesting 1.4 million ha as of 2003 (McDaniel et al. 2004, Glenn et al. 2005, Graf 1978). Today *Tamarix* is the dominant vegetation type along many southwestern (Stromberg et al. 2005) and Oklahoma rivers (Anderson and Masters 2007). As early as the 1940s, literature suggests there is no single effective *Tamarix* control method (McDaniel et al. 2004). The main management focus has been to eradicate *Tamarix* using a combination of several costly and time-consuming methods. Millions of dollars have and will be spent in an effort to control *Tamarix*. In many cases removal of *Tamarix* is not sufficient for the return of native species (Shaforth et al. 2008). Furthermore, recent research supports the idea that *Tamarix* may be controlled with the return of a natural flow regime (Stromberg et al. 1993, Stromberg 1997, Sher et al. 2002, Nagler et al. 2005b). It is unclear whether a natural flow regime alone will be sufficient for the return of native trees to the river system and control the spread of *Tamarix* (Glenn et al. 2005). Shaforth et al. (2008) recommend removal of the exotic species followed by a natural flow regime or mimic a natural flow to encourage the reestablishment of native trees and control *Tamarix*. To mimic a natural flow regime, these flows would require a magnitude large enough to create bare moist germination sites; flooding synchronized with the seed dispersal period of native trees; gradual flood recession for ample water supply to seedlings; and a reduction in subsequent floods until natives are of adequate size to withstand physical damage from flooding (Cooper et al. 2003).

Scientists have not concluded as to whether *Tamarix* is out-competing natives or, due to extensive river damming, the habitat is no longer suited for native establishment. However, it is well documented that a highly diverse plant community is less likely to be invaded (Pickett 1985). Species richness of a community is related to its level of disturbance. Highest species richness is found with intermediate disturbance. However, lowest species richness is found under high and low disturbance levels (Pickett 1985). For example, increasing flows often promote invasions by removing existing species through erosion, therefore reducing plant species richness and thereby reducing competition from other species. However, decreasing floods (low disturbance) also promote *Tamarix* invasions by reducing base flow, water tables and sediment delivery while increasing soil salinity, as observed on regulated rivers (Sher et al. 2002, Glenn et al. 20005, Cooper et al. 2003). *Tamarix*, a facultative halophyte/phreatophyte and stress-tolerant species, has adapted very well to these changes on regulated rivers, especially elevated salinity (Glenn et al. 2005). Xeric conditions encourage the spread of *Tamarix* and reduce available habitat for the native trees. Therefore, even if *Tamarix* is eradicated along the rivers without flooding, the elevated soil salinity remains, hindering growth of salt intolerant native trees. However, an intermediate flood regime could remove excess salts and increase species richness. Both *Tamarix* and native trees have adapted to a flood regime, however *Tamarix* may be better adapted to exploit available substrate late in the season, while native species require a spring flood regime for successful germination (Sher et al. 2002). The exact flood frequency or magnitude to control *Tamarix* is unclear (Sala et al.1996, Stromberg 1996). For flooding to be a *Tamarix* management tool, the frequency and magnitude of flooding should be fully understood (Stromberg et al. 2005). Therefore, perhaps a concurrent reduction in *Tamarix* and soil salinity will occur if the optimal flood frequency and magnitude are achieved through a planned flood (Sala et al.1996, Busch and Smith 1995, Shafroth et al. 1995). Additional research is needed to determine whether all riparian areas may benefit from a planned spring flood regime (Sher et al. 2002).

Despite extensive previous research on *Tamarix*, there are no studies to my knowledge that have addressed the effects of flooding and salinity on *Tamarix* in a zonal plant community in an inland salt habitat. The Salt Plains National Wildlife Refuge (SPNWR) offers a unique habitat for gradient studies. The Salt Fork of the Arkansas and its tributaries meander throughout the extreme hypersaline flats where *Tamarix* dominates around the margins and creek channels. The refuge habitat contains these components for this study: *Tamarix* vegetation cover, hypersaline soil and soil disturbance by erosion and/or deposition.

The dynamics of a natural river system are complex and unique to its region. The zonation of riparian vegetation is largely determined by the flood regime (Stromberg et al. 2005), and salinity gradient (Ungar 1968). In a riparian system, flood disturbance decreases (Stromberg et al. 2005) and salinity increases (Ungar 1968) with increasing distance from the river channel, creating a shift in species composition along a gradient (Ungar 1968, Stromberg et al. 2005). SPNWR contains these abiotic and biotic factors along a gradient for the study of fluvial disturbances and soil salinity effects on *Tamarix*.

I have examined *Tamarix* density and soil salinity patterns along a gradient at the transition from the salt flats to the vegetation zone during a two-year study period. These data were related to local precipitation and reservoir release records. This may shed light on the mechanisms by which *Tamarix* species invade, multiply and retain dominance (Busch and Smith 1995).

METHODS

STUDY SITES

The Salt Plains National Wildlife Refuge (SPNWR) is located in Alfalfa County in northwestern Oklahoma covering approximately 65 km^2, surrounded by agricultural fields and mixed grass prairies. Johnson (1972) describes this area as a Quaternary formation with underlying saturated Permian brine deposits wicking up to the surface. The rivers and creeks typically drain southeasterly, sporadically creating ephemeral saline floodplains across the refuge (Fig. 2, Baalman 1965). The low elevation and continental climate generate a mean daytime high of 36˚C in summer and a mean low of -5˚C in winter (Oklahoma Climatological Survey) with a mean growing season of 197 days. The annual precipitation at the SPNWR averages approximately 66 cm with large variance, with modes in May and October (Mesonet 2003, Baalman 1965). The SPNWR is the largest saline seep in Oklahoma, where sparse vascular vegetation on the hypersaline flats is limited to only a few salt tolerant species. The riparian zones are dominated by the highly salt tolerant *Tamarix* species that may withstand salt up to 44 mmhos/cm (Glenn et al. 1998). The most abundant plant species found in my study sites (nomenclature follows USDA Plants Database) are: *Distichlis spicata* var. *stricta* (saltgrass), *Eragrostis* spp. (love grass), and *Tamarix chinensis* and *T. rammosisama* (collectively, salt cedar or tamarisk).

To represent *Tamarix* density on the SPNWR thirteen sites, approximately 0.2 hectare in size, were established in riparian zones around the perimeter of the salt flats. The exact coordinates at each site were determined using a random number table matching random numbers with last two digits in latitude. Within each site two 40 meter transects were spaced 25 meters apart oriented perpendicular to the steams edge and vegetation interface of the salt flats (Fig.1)(Krebs 1998). Each transect was divided into twenty 4 m^2 (2 x 2 m) quadrats indicating the sampling unit (n = 520). Sites one and two are dominated by prairie species, *Ambrosia phsilostachya* (perennial ragweed), and *Eragrostis* spp. (love grass), with the lowest *Tamarix* stem density. Sites three, four, five and six are dominated by *Tamarix* and are highly disturbed, exposed to frequent scouring and sediment delivery of the meandering Salt Fork River of the Arkansas River. The southernmost sites seven, eight, and nine are dominated by *Tamarix* with a *Distichlis spicata* var. *stricta* (saltgrass) understory positioned perpendicular to Spring creek. Sites ten and eleven are located on the West side of the refuge on Clay Creek, a tributary of the Salt Fork of the Arkansas River. Sites twelve and thirteen are also on Clay creek farthest into the salt flats here, *Tamarix* is the only vascular plant species.

SAMPLING

I collected quantitative measurements in 2006 and 2007 of all trees, shrubs and herbaceous vegetation within each quadrat of each transect, totaling 520, 4 m^2 quadrats. In 2006, as a preliminary attempt to relate *Tamarix* density to soil properties, using a soil probe, I collected one composite sample at each site in transect one. The composite sample was made from five soil cores 2 cm in diameter, depth 0-10 cm, following Simple Random Sampling procedures (Carter 1993; n=13 sites). However, in 2007 I collected one, five soil core composite sample using a 2 cm diameter core, depth 0-10 cm in all transect at 2, 6, 16, 26, and 36 meters (n=127, i.e. 5 samples x 26 transects, less three lost samples).

All vascular plants within each quadrat were identified to species. When multiple species of the same genera were identified only the genus was used. Cover percentages based on visual estimate, including overlaps, were assigned to one of the following categories: rare, < 1 %, 1-2 %, 2-5 %, 5-10 %, 10-25 %, 25-50 %, 50-75 % or 75-100 %. Within each quadrat, density, diameter, and height were recorded only for *Tamarix* spp. Live density was calculated from green leafy plants with roots. Density of dead *Tamarix* was based on leafless stems with no root system; diameter was recorded using a Vernier caliper 4 cm above the soil surface on each stem, and crown height was recorded using a meter stick. Distance to nearest creek was calculated from quadrat one in each transect using the ArcMap 9.1 meter tool.

ANAYLSES

Soil samples were placed in whirl pack bags and dried to constant weight at 48 ºC. The surface soil (0-10 cm) samples were analyzed for electrical conductivity (EC) by Oklahoma State University Soils lab in 2006 and Brookside Laboratories, Inc. (New Knoxville, Ohio) in 2007. Vegetation data from 2006 and 2007 and all soil properties were analyzed using SPSS 15 statistical software’s bivariate Pearson two-tailed correlation including mean, standard deviation, sum of squares cross product and covariance descriptive analyses. Significant correlations were then analyzed using regressions in Microsoft Excel (2000).

RESULTS

From 520 samples collected in my 2006 through 2007 research I identified 40 vascular plant species. Table 1 (2006) and Table 2 (2007) list species from highest to least relative abundance based on percent cover. In both years the most abundant species were graminoids with *Distichlis spicata* var. *stricta* (saltgrass) the most abundant species in 2006 and *Eragrostis* spp. (lovegrass) in 2007. Species richness increased during the two-year study, from 20 species in 2006 to 40 species in 2007.

Tamarix mean stem density within quadrats decreased from 3.01 stems m^{-2} in 2006 to 1.15 stems m^{-2} in 2007. *Tamarix* mean stem density increased within transects in 2006 with increasing distance away from barren salt flats (Fig. 3, $p<0.01$: see Fig 1 for explanation of transect orientation). In 2007 maximum density occurred in the middle of transect with 2nd order polynomial regression line showing a weak correlation (Fig. 3, $p<0.05$). The change in live stem densities from 2006 to 2007 show a strong negative correlation between *Tamarix* density during the two year study period, inferring a significant reduction in *Tamarix* stem density from 2006 to 2007 (100% in some quadrats) with little recruitment (Fig. 4, $p<0.01$). However, Figure 5 shows a strong negative relation between change in dead *Tamarix* stem density in 2006 and 2007. In 2006 there was a higher density of visible dead *Tamarix* plants than in 2007 (Fig. 5, $p<0.01$).

Tamarix mean height in 2006 shows no significant correlation between distance from the salt flats or creek; however, in 2007 there was a positive correlation between *Tamarix* mean heights with increasing distance from the salt flats (Fig 6). Mean *Tamarix* height was less than 2 m during the study period (Fig. 6). Between *Tamarix* mean stem density and distance from nearest creek a weak negative correlation exists in 2006 ($p<0.05$). However, in 2007 it was not significant (Fig.7, $p<0.10$).

Tamarix density in 2007 decreased as EC (electrical conductivity) increased throughout refuge, but with a wide range of scatter (Fig. 8, $p< 0.05$). In 2007 mean EC increased as distance increased from nearest creek again with large scatter (Fig. 9, $p<0.01$). In 2007, mean soil salinity decreased with distances from the salt flats along the transect, regression fit showing a weak negative correlation (Fig. 10, $p<0.05$). However, soil salinities were significantly higher in 2006 (78.7 mmhos/cm ± 59.4) than in 2007 (8.5 mmhos/cm ± 9.8; two-tailed Students t test for unequal variances; $p = 0.001093$). *Tamarix* mean stem densities show a weak negative correlation with EC in 2006, but not significant in 2007 (Fig. 11).

Precipitation at the nearby Oklahoma Mesonet station and consequently the water flowing into the Great Salt Plains dam varied significantly between years (Fig. 12). The average annual precipitation for Alfalfa County is 66 cm (Mesonet 2009). In 2005, annual rainfall was about average with 70.8 cm and the twelve month average dam inflow was 28,409 acre-ft. Precipitation (39.8 cm) and lake inflow (6,512 acre-ft) were anomalously low in 2006. In contrast, 2007 was a relatively high inflow year (52,551 acre-ft) supplied by 89.4 cm total annual precipitation occurring mostly in the warmer months.

DISCUSSION

In the vast majority of quadrats, *Tamarix* live and dead stem densities decreased from 2006 to 2007, while species richness increased. *Tamarix* density decrease in 2007 may have reduced competition, allowing an increase in *Eragrostis* spp. in particular and many other species (cf. Tables 1 & 2). According to Birken (2006) *Tamarix* establishment is correlated with large peak flows followed by smaller peak flows. This phenomenon was observed in 2005 and 2006. Precipitation in 2005 was about average, a large peak inflow occurred in June (103,864 acre-ft/mo, Fig. 12) that may have reworked the creek bank. The flood may have deposited fine moist sediment during *Tamarix* seed release climax, producing an ideal bare substrate for seed germination. Precipitation was chronically low in 2006, with smaller peak flows than 2005 (Fig. 12). The smaller peak flows and drought conditions in 2006 may have allowed *Tamarix* to increase in density due to its drought and high salt tolerance. However, 2007 was a relatively high inflow year with 89.4 cm total annual precipitation, occurring mostly in the warmer months. *Tamarix* plants established in 2006 were relatively small (under 2 m, Fig. 6); at this size *Tamarix* apparently was unable to tolerate the scouring and sediment burial of the large peak flows in 2007 (221,454 acre-ft/mo, Fig. 12). The relatively small *Tamarix* plants were uprooted and washed away or buried beneath sediment. The peak flow of 2007 again occurred during June, the peak-growing season for *Tamarix.*

The perpendicular position of transects has quadrat one (0-2 m) on the salt flats and quadrat 20 (38-40 m) closer to creek. The largest reduction in *Tamarix* stem density was toward the creek end of transects. This also suggests *Tamarix* mean stem density may have been reduced due to the increased flooding in 2007, because of its proximity to the creek.

The decrease in dead *Tamarix* stem density (0.44 m^{-2} in 2006 to 0.06 m^{-2} in 2007) may have been due to the removal of the small dead stems through scouring or burial beneath sediment during flood events. Higher *Tamarix* stem densities in 2006 were observed within ~170 m from the creek but lower *Tamarix* stem densities in 2007 suggest high vulnerability due to flooding. Flooding in late summer actually promotes *Tamarix* invasions by forming new sandbars devoid of vegetation, ideal for *Tamarix* seedling establishment (Sher et al. 2002). However, if these seedlings are still relatively small (< 2 m) during the next flooding event, flooding appears more detrimental to *Tamarix* then salinity (Glenn et al 2005).

SPNWR soil salinity is highly variable in space and time, confirmed by significantly different salinities in the two years of the study period where mean EC was 78.7 mmhos/cm in 2006 and 8.5 mmhos/cm in 2007. High salinities undoubtedly play a role in *Tamarix* stem density; virtually no *Tamarix* occurred at >25mmhos/cm (farthest from the creek) and highest *Tamarix* mean stem densities were at < 5 mmhos/cm (closest to creek) in 2007 (Fig.8). While gouging and burying *Tamarix,* flooding flushes the soil salts away into the nearest creek, reducing soil salinity and *Tamarix* stem density across the refuge. Sher (2002) found similar results for *Tamarix* on the Middle Rio Grande, New Mexico.

The bulk of my study occurred during a dry year and only showed the results of one above average flood in 2007. A flow gauge at each transect end would be useful to determine the exact flow magnitude needed to eradicate *Tamarix* during different life stages.

The preliminary steps in my research were taken to evaluate the correlations between *Tamarix* flooding and salinity. Future studies at the SPNWR should target vegetation and soil sampling during peak and minimum flow periods to better document establishment and mortality. Collection of aboveground biomass before and after a large flood (100,000 acre-ft/mo) would also help to determine *Tamarix* reduction or establishment. Soil texture may be a better indicator than salinity for predicting future invasions (Cooper et al. 2003).

These findings on *Tamarix* intolerance to flooding and tolerance to salinity may help to design a *Tamarix* flood control protocol. Therefore, establishing the linkage between successful or unsuccessful *Tamarix* establishment, and determining the flood frequency and magnitude required to increase or decrease *Tamarix* stem numbers (Birken and Cooper 2006).

All species exhibit a salt tolerance range; *Tamarix* in my study had a very broad tolerance range (Fig. 11). However, the duration and magnitude of salinities can be extremely detrimental to all species. Glenn (2005) found *Tamarix* to withstand salinities up to 44 mmhos/cm, classifying it as a true halophyte, but even halophytes have a limit. In these extreme salt conditions, one survival strategy for seeds is to germinate when salinities are low, explaining the higher *Tamarix* densities near the creeks (Figs. 7,8&11). The native tree species of riparian areas have adapted to disturbance by producing seeds only in early spring. *Tamarix* has not adapted this strategy; it produces seeds from mid spring to late fall, when seedlings are exposed to torrents of water in the common and sometimes frequent Oklahoma thunderstorms. It is plausible that flooding in 2007 reduced *Tamarix* stem density in my study. Due to the high spatial and temporal variability in soil salinity, effects of salinity are less obvious. It may mainly control the distribution limits. This soil salinity variability may also explain the frequent occurrence of seedlings at the edge of the salt flats, which never appear to become permanently established (personal observation).

The present research suggests some critical ideas for directing water management and floodplain restoration. First, in a freshwater riparian environment, salinity will not control the spread of *Tamarix*. However, flooding will reduce the establishment of *Tamarix* if it occurs when *Tamarix* plants are small. It is necessary to eradicate *Tamarix* before it reaches a size resistant to flood stress, probably less than 2 m. Unfortunately, if *Tamarix* is not controlled at an early age, it will dominate rivers, potentially changing the hydrological processes and replacing the native riparian species, resulting in a homogeneous riparian ecosystem dominated by an exotic tree species.

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Table 1. Vascular plant species identified within all 520 quadrats and 26 transects in 2006 on the SPNWR. Species are arranged from most to least abundant based on mean percent cover in quadrats.

Species	Relative Abundance
Distichlis spicata var. *stricta* (saltgrass)	0.162
Tamarix spp. (saltcedar, five-stamen tamarisk)	0.160
Suaeda calceoliformis (pursh seepweed)	0.030
Sporobolus spp. (dropseed)	0.252
Schizachyrium scoparium (little bluestem)	0.022
Xanthium strumarium (rough cocklebur)	0.021
Chenopodium album (lambsquarters)	0.016
Ambrosia psilostachya (Cuman ragweed)	0.102
Calamovilfa gigantea (giant sandreed)	0.010
Bromus tectorum (cheatgrass)	0.007
Rhus aronmatica (fragrant sumac)	0.007
Andropogon spp. (bluestem)	0.005
Panicum virgatum (switchgrass)	0.005
Euphorbia marginata (snow-on-the-mountains)	0.004
Sesuvium verrucosum (verrucosum seapurslane)	0.004
Helianthus spp. (sunflower)	0.004
Polypogon spp. (rabbitsfoot grass)	0.002
Desmanthus illinoensis (Illinois bundleflower)	0.0004
Plantago spp. (plantain)	0.0003

Table 2. Vascular plant species identified within research transects in 2007 on the SPNWR. Species are arranged from most to least abundant based on percent cover.

Species	Relative Abundance
Eragrostis spp. (lovegrass)	0.158
Tamarix spp. (saltcedar, five-stamen tamarisk)	0.114
Distichlis spicata var. *stricta* (saltgrass)	0.113
Suaeda calceoliformis (pursh seepweed)	0.053
Ambrosia phsilostachya (perennial ragweed)	0.050
Bromus tectorum (cheat)	0.048
Spartina pectinata (prairie cordgrass)	0.040
Sporobolus spp. (dropseed)	0.036
Helianthus spp. (sunflower)	0.029
Polygonum spp. (Pennsylvania knotweed)	0.028
Xanthium strumarium (rough cocklebur)	0.027
Cyperus strigosus (false nutgrass)	0.022
Andropogon spp. (bluestem)	0.022
Echinochloa spp. (barnyard grass)	0.021
Polypogon spp. (rabbitsfoot grass)	0.020
Iva annua (sumpweed)	0.020
Elymus canadensis (Canada wild rye)	0.0182
Chenopodium album (lambsquarters)	0.0174
Schizachyrium scoparium (little bluestem)	0.0164
Salsola tragus (Russian thistle)	0.0144

Table 2. continued

Species	Relative Abundance
Conyza canadensis (horseweed)	0.0141
Medicago spp. (alfalfa)	0.0140
Scirpus spp. (bulrush)	0.0123
Euphobia marginata (snow-on-the-mountains)	0.009
Calamovilfa gigantean (giant sand reed)	0.009
Sesuvium verrucosum (verrucosum seapurslane)	0.009
Desmanthus illinoensis (Illinois bundleflower)	0.008
Symphyotrichum ericoides (white heath aster)	0.008
Grindelia squarrosa (curlycup gumweed)	0.004
Gnaphalium obtusifolium (rabbit-tobacco)	0.004
Panicum vigatum (switchgrass)	0.003
Hordeum spp. (wild barley)	0.003
Rhus aronmatica (fragrant sumac)	0.001
Amaranthus retroflexus (redroot amaranth)	0.001
Plantago spp. (plantain)	0.001
Salix nigra (black willow)	0.0008
Rotala ramosior (lowland rotala)	0.0006
Fragaria vesca (woodland strawberry)	0.0005
Solidago canadensis (Canada goldenrod)	0.0005

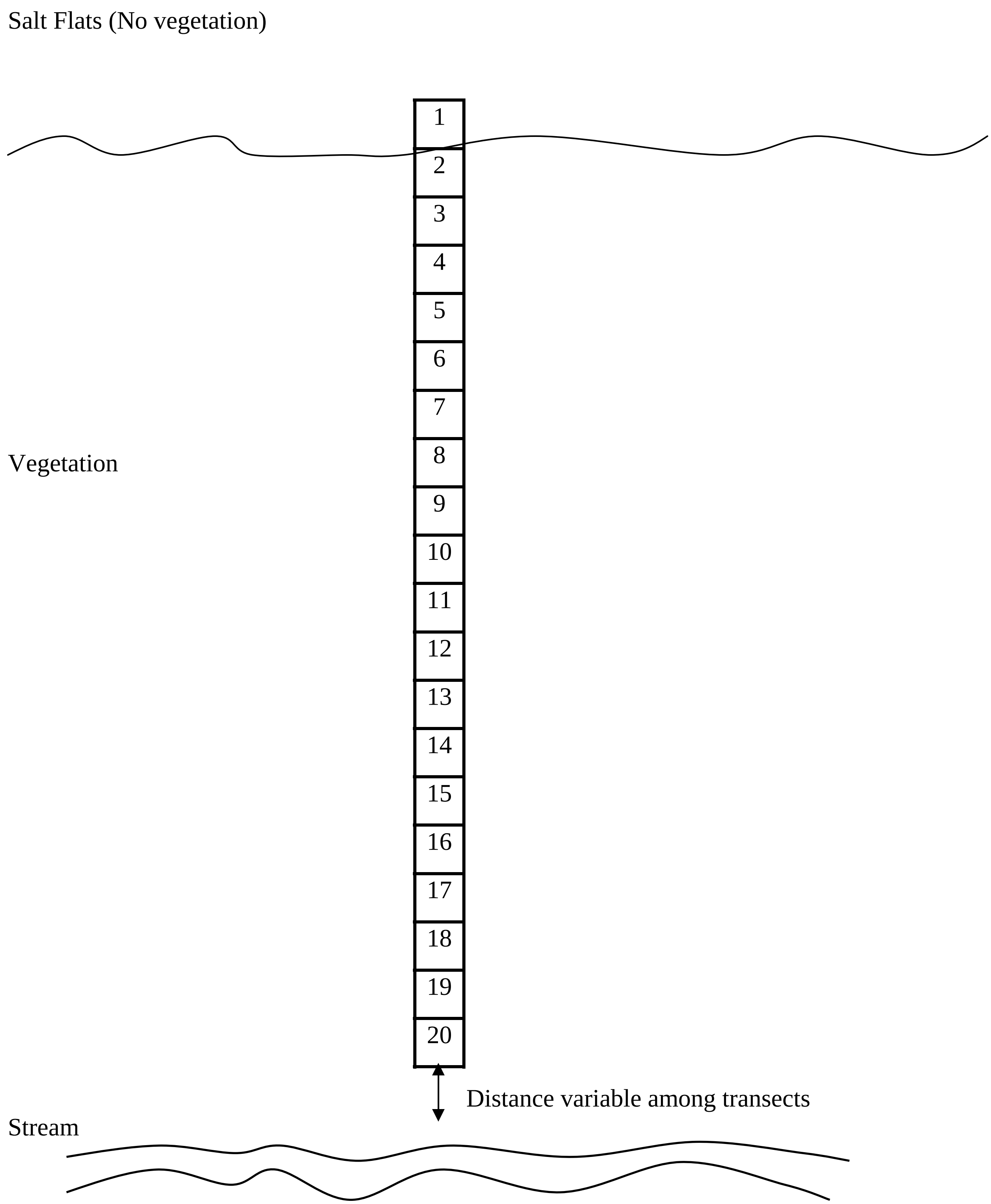

Figure 1. Conceptual diagram depicting 20 2 x 2 m quadrats within transect. Each transect begins perpendicular to the edge of the salt flats and ends closer to a stream.

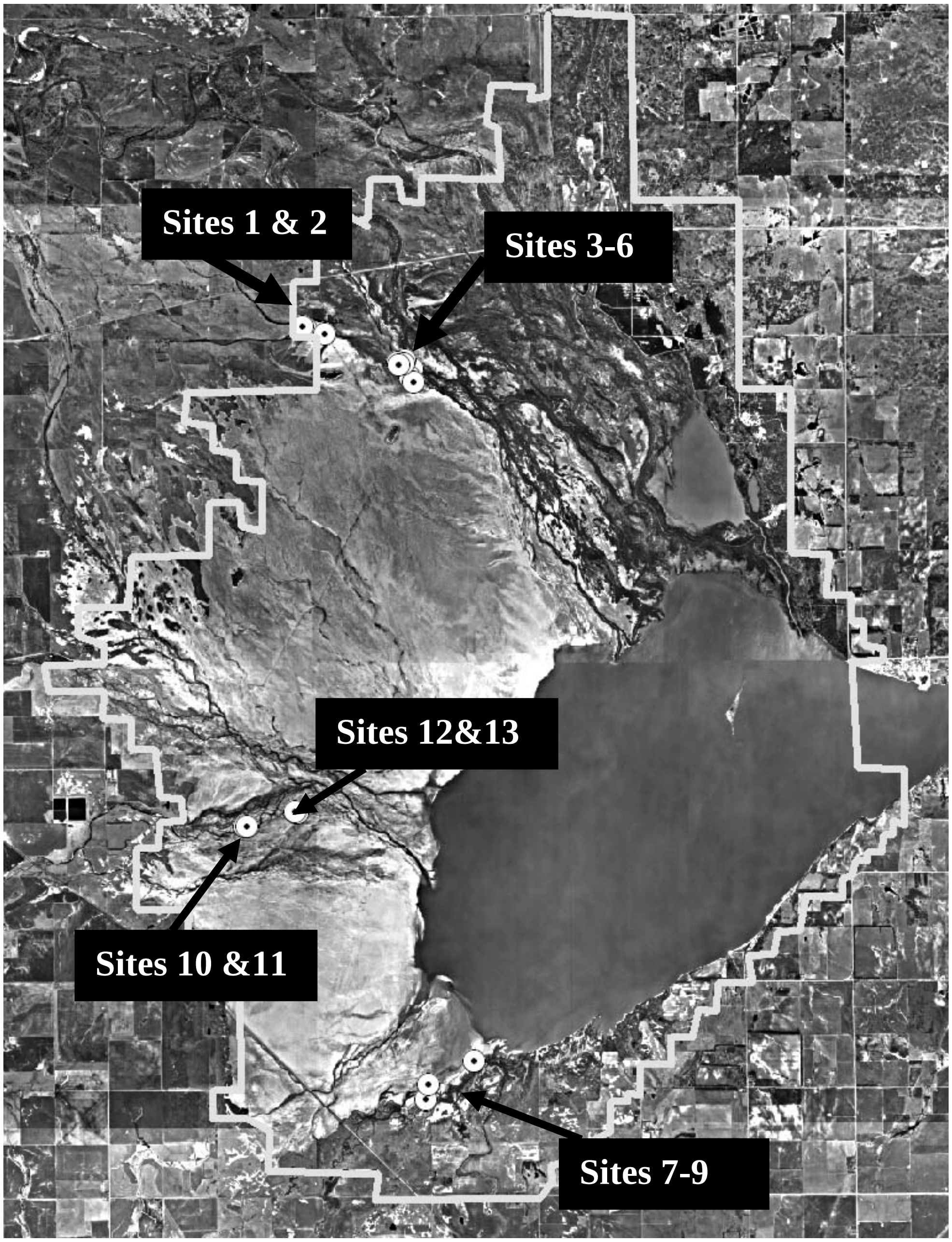

Figure 2. Aerial imagery from the U.S. Fish and Wildlife Services 1995 depicting SPNWR and boundaries. White circles indicate research sites, and white lines indicate the refuge boarder.

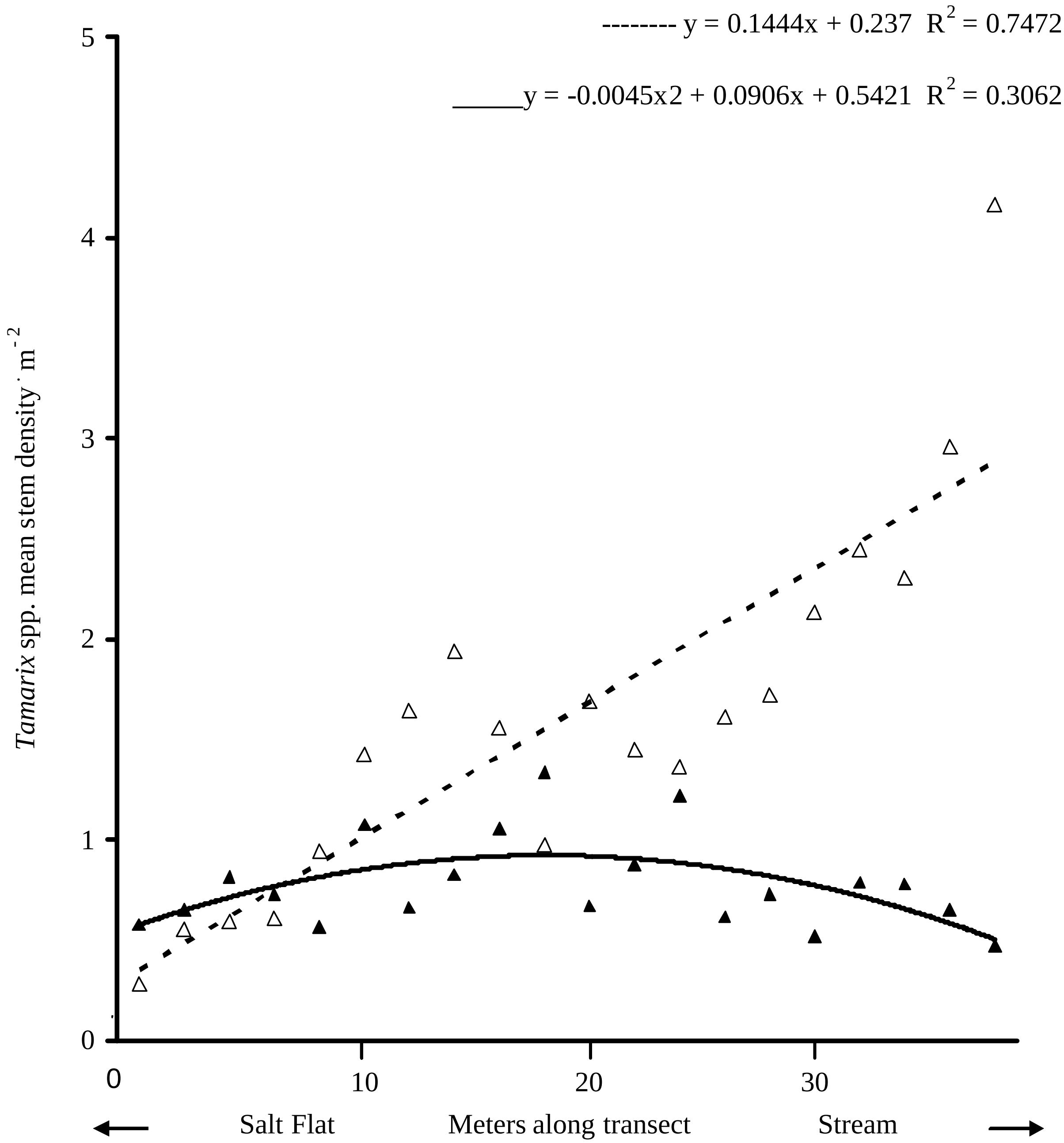

Figure 3. *Tamarix* spp. mean live stem density along transect across all sites. Hollow triangles and dashed regression line represents 2006 data ($P<0.01$, N= 20). The solid triangles and solid regression line (2[nd] order polynomial used to obtain best fit) represents 2007 data ($P<0.05$, N= 20).

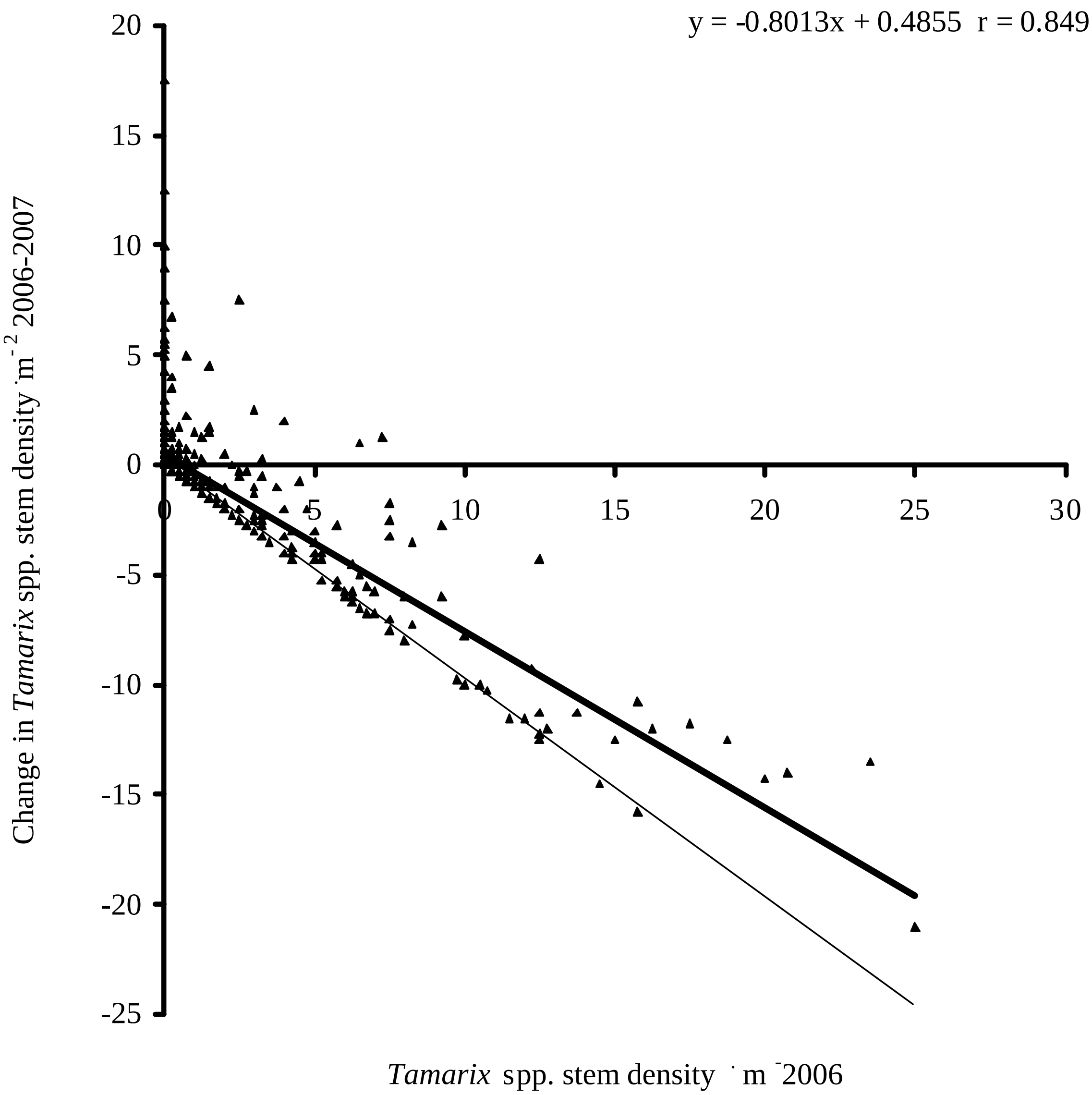

Figure 4. The change in *Tamarix* spp. live stem density from 2006 to 2007 across all sites and qudrats. P < 0.01, N = 520. Thick line is the regression fit. Fine line indicates 100% mortality from 2006 to 2007 for reference. Positive values indicate net recruitment while negative values reflect net loss.

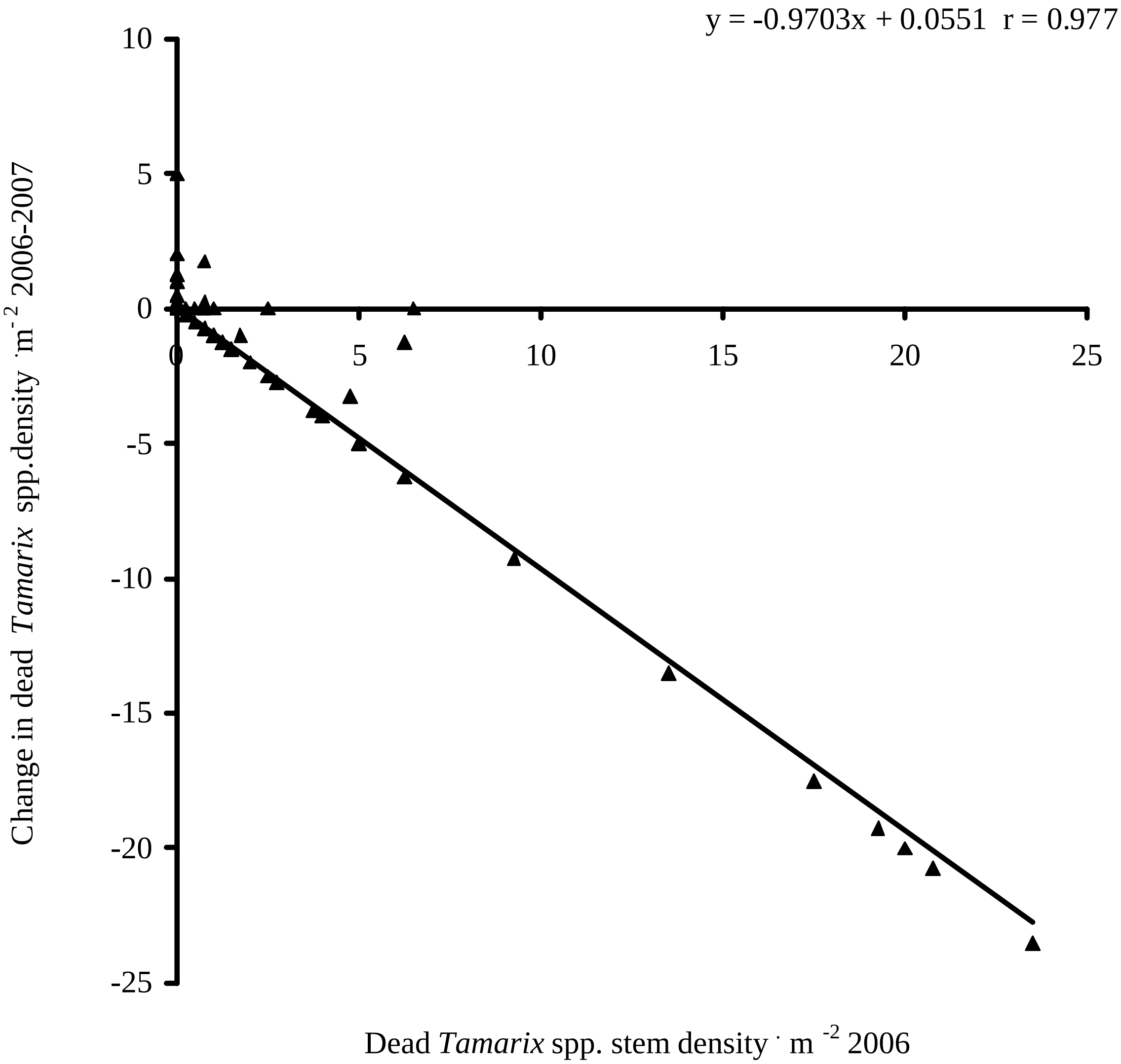

Figure 5. The change in dead *Tamarix* spp. stem number density from 2006 to 2007 within all transects. $P < 0.01$, $N = 520$. Line is the regression fit. Positive values indicate net recruitment while negative values reflect net loss.

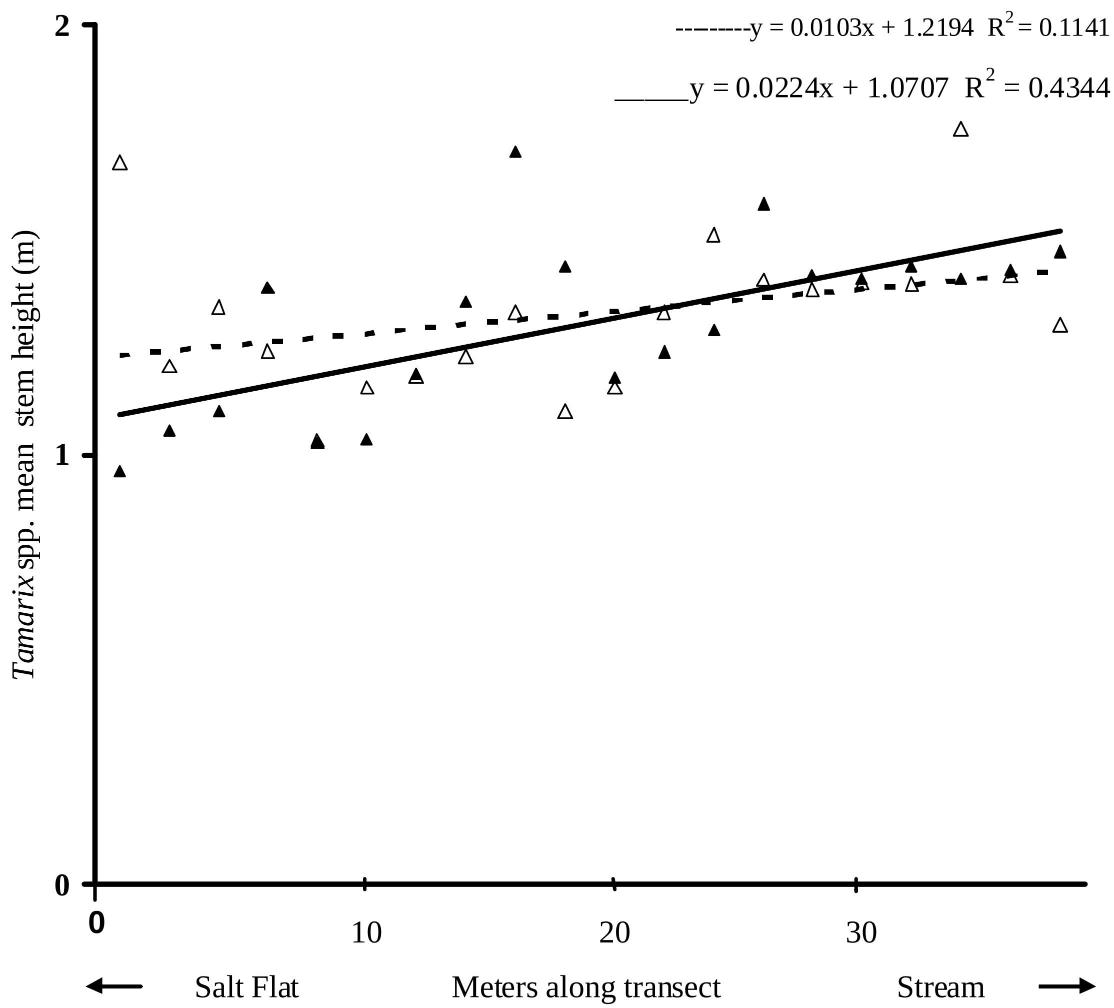

Figure 6. *Tamarix* spp. mean height along the distance of the transects across all sites in 2006 (N = 20, NS) and 2007 (N = 20, P < 0.01). The hollow triangles and dashed trend line represents 2006 data and solid triangles and solid trend line represents 2007 data.

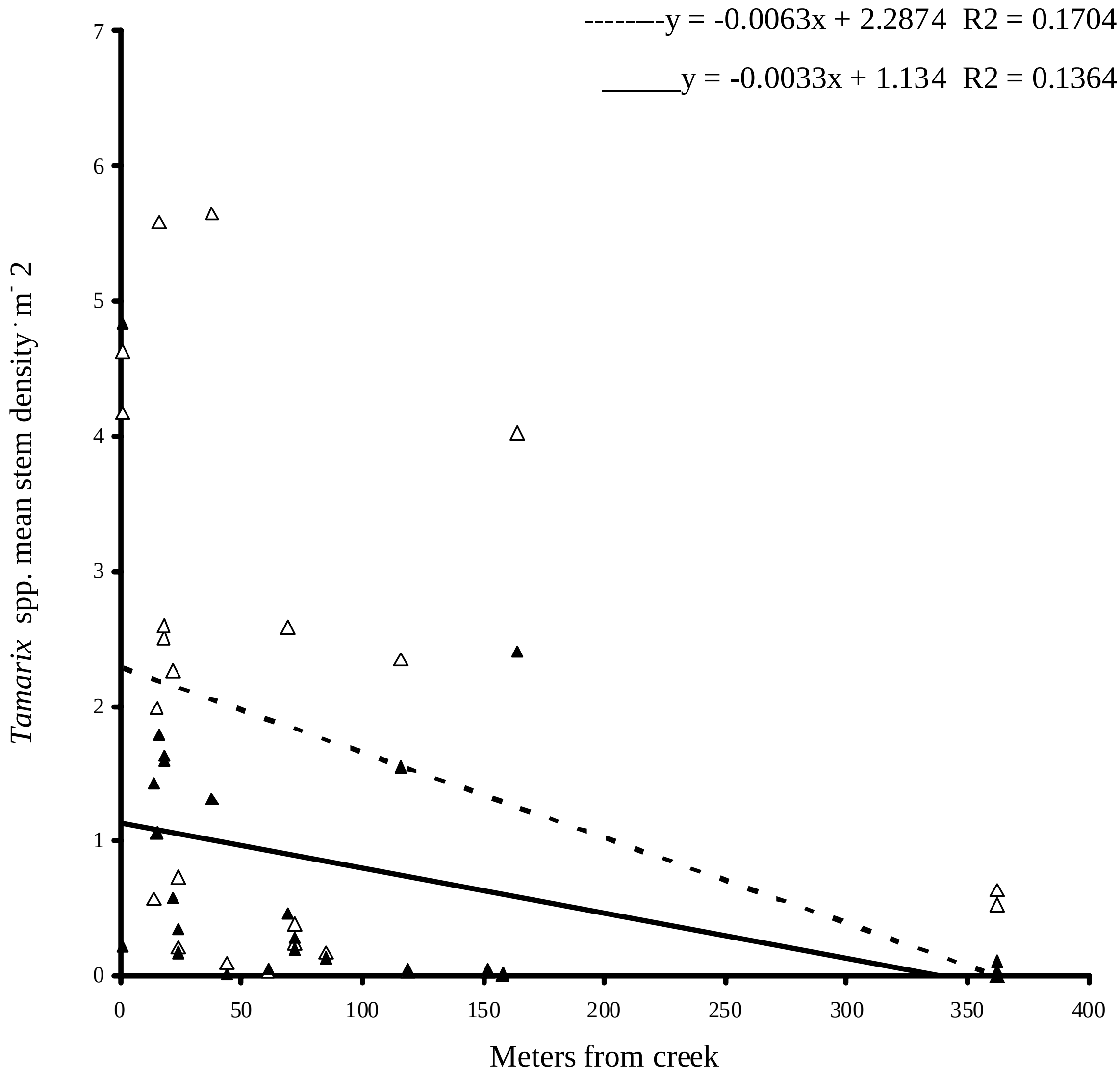

Figure 7. The relationship between *Tamarix* spp. mean live stem density and distance from the nearest creek. The hollow triangles and dashed regression line represent 2006 data (P< 0.05, N = 26) and solid triangles and solid regression line represent 2007 data (NS).

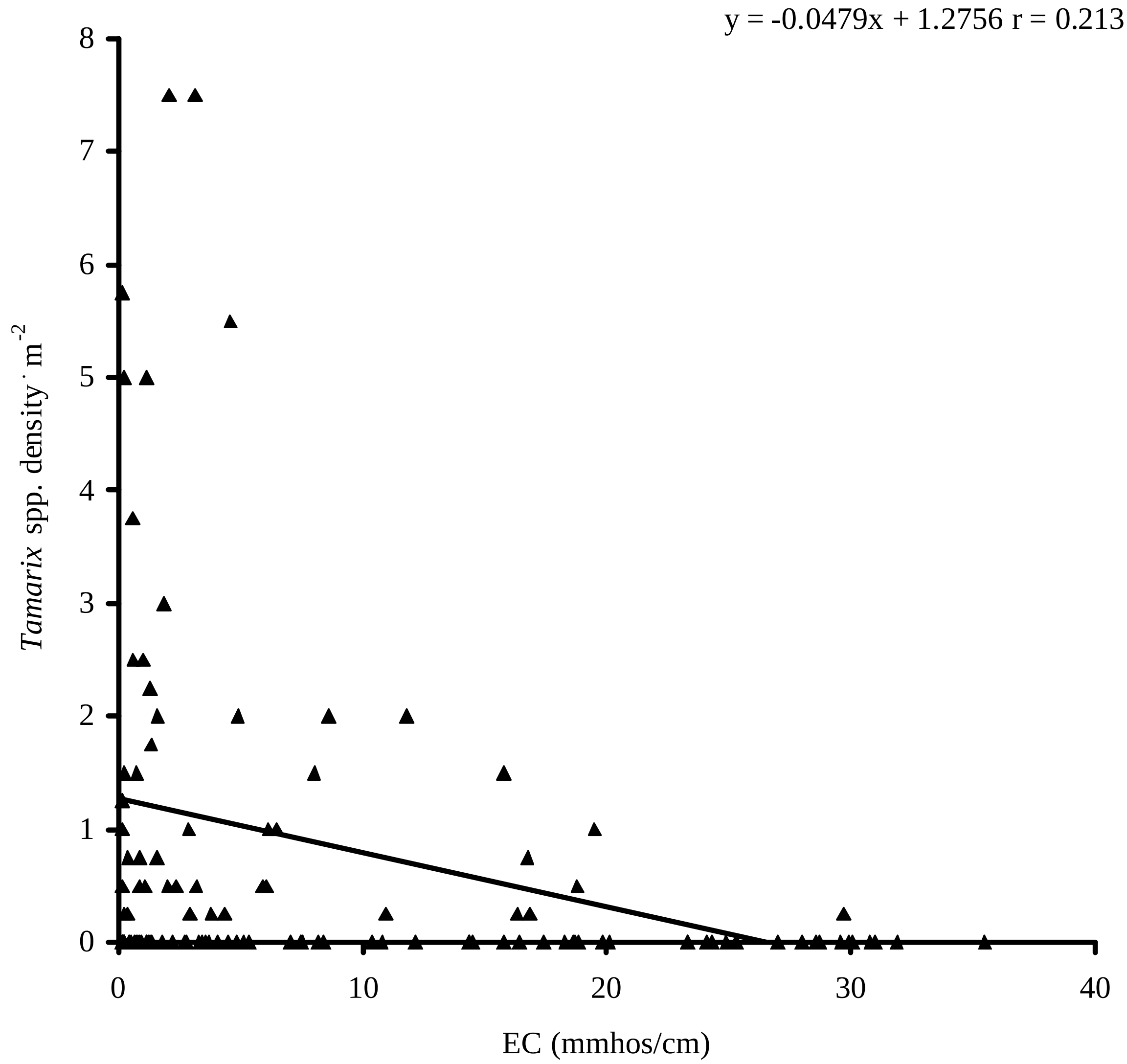

Figure 8. The relationship between *Tamarix* spp. stem density and electrical conductivity (EC) in 2007 within individual quadrats where soil samples were collected (P< 0.05, N = 127).

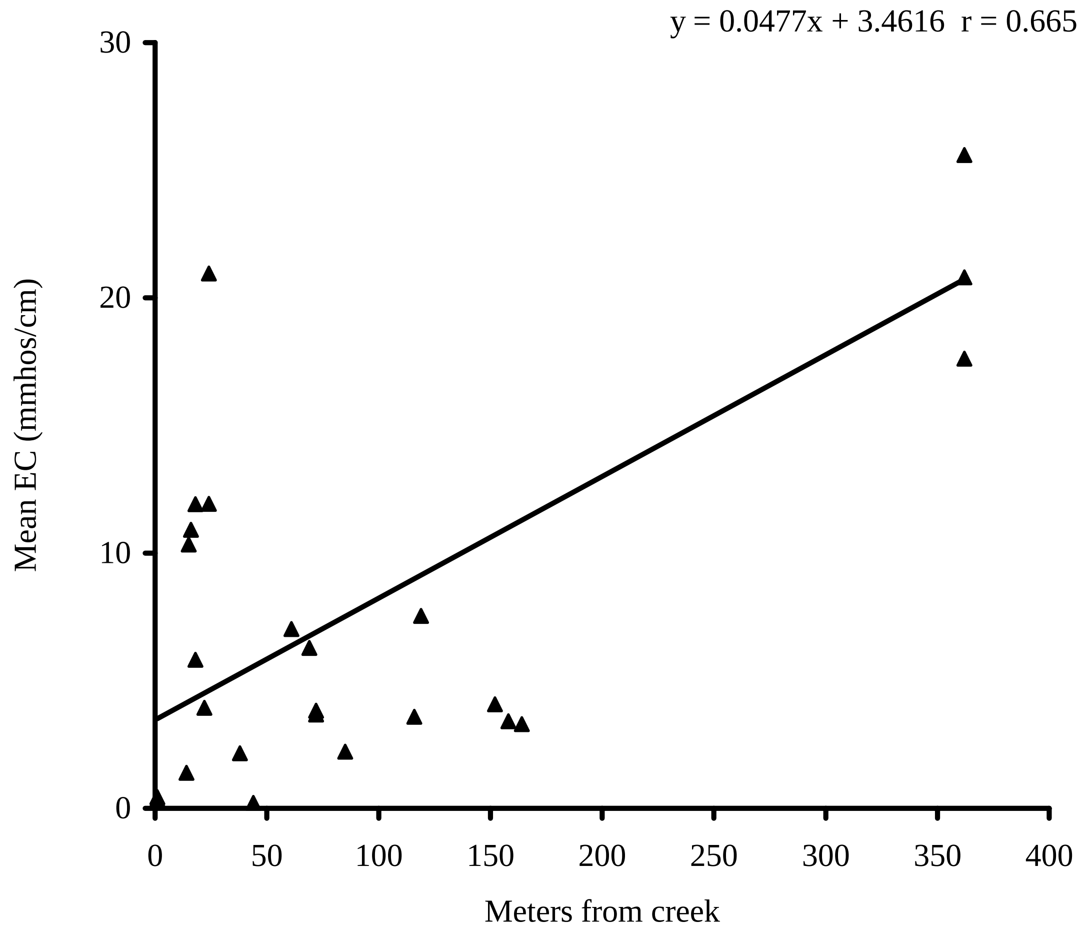

Figure 9. The relationship between mean EC in each transect and meters from the nearest creek in 2007 P< 0.01, N = 26.

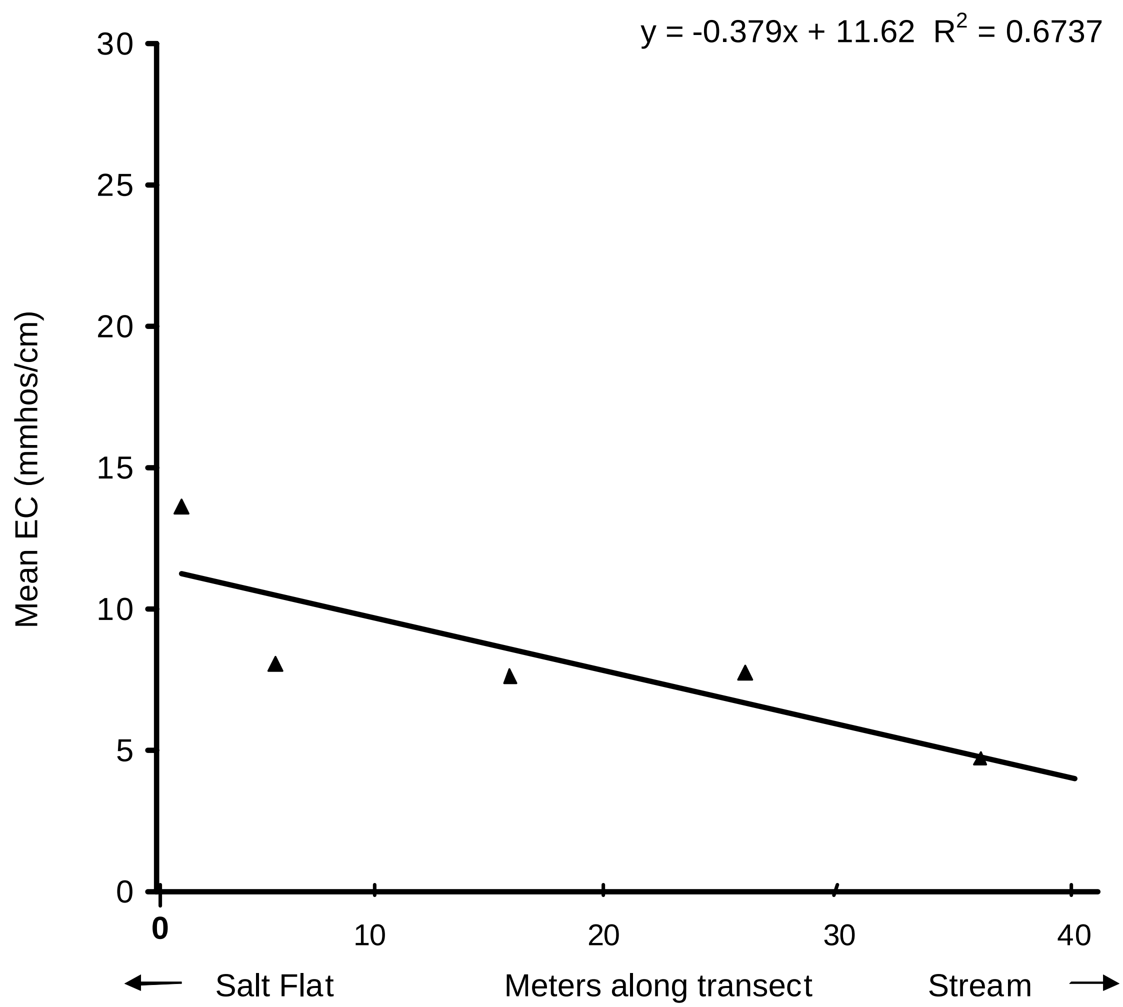

Figure 10. Mean EC along transects across all sites in 2007 ($P < 0.10$, $N = 5$).

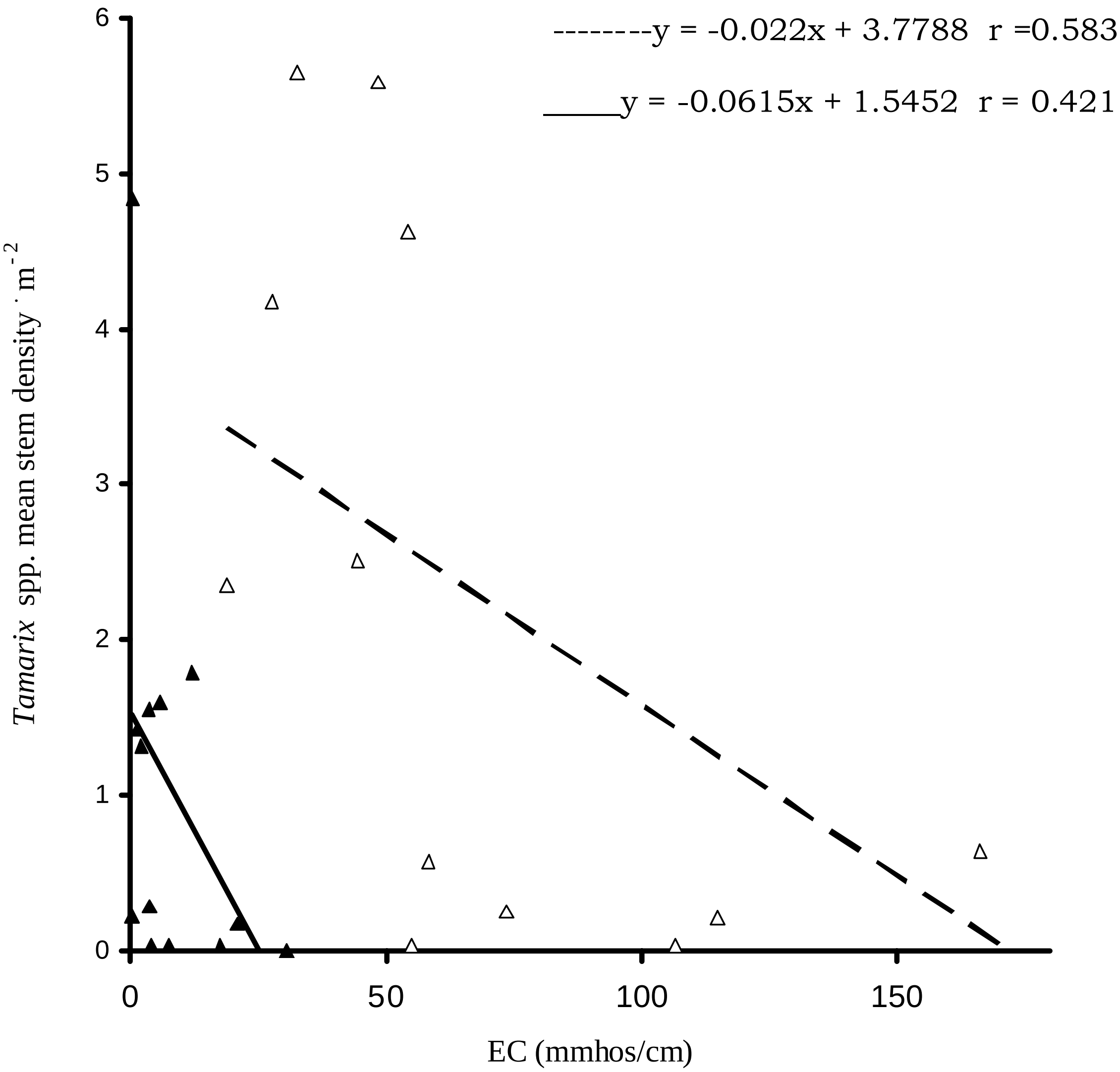

Figure 11. Corresponding transect soil salinity data from 2006 and 2007 (Note that different soil sampling procedures were used in 2006 and 2007 (see methods)). The hollow triangles and dashed regression line indicate the relationship between *Tamarix* stem number and soil electrical conductivity (EC) in 2006. ($r = 0.583$, $P < 0.05$, $N = 13$). The solid triangles and regression line indicate the relationship between *Tamarix* stem number and EC in 2007. ($r = 0.421$, not significant, $N = 13$).

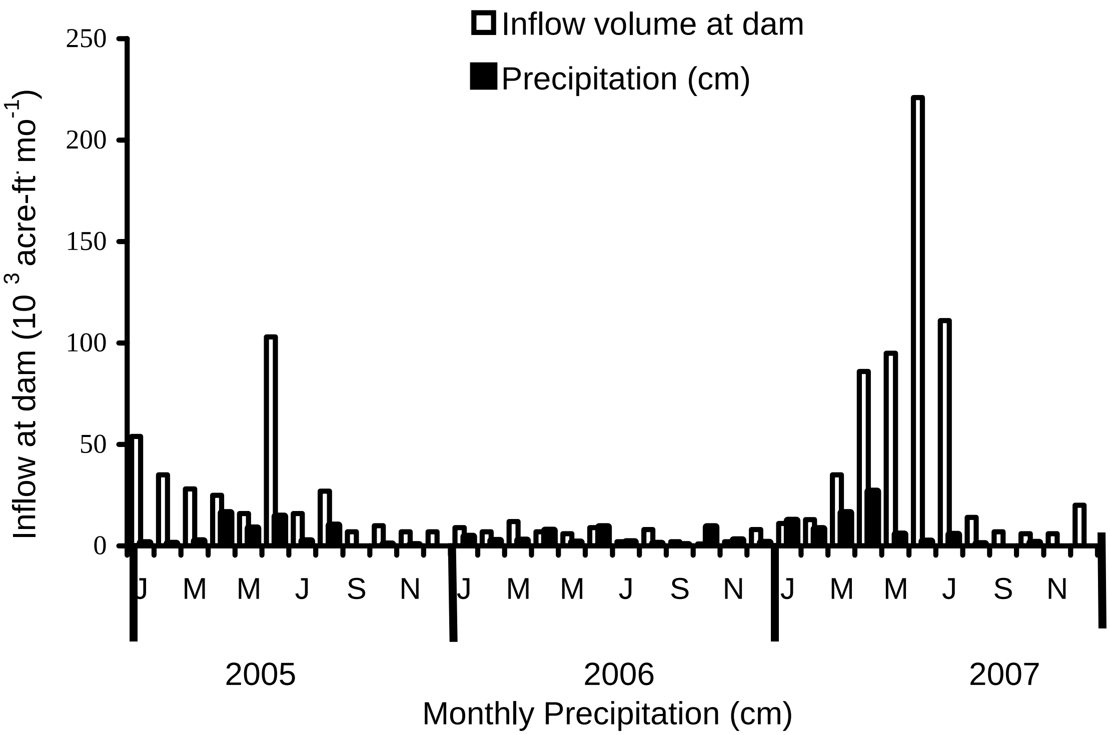

Figure 12. Monthly totals of water flowing into the Great Salt Plains dam and Cherokee Mesonet station monthly totals of precipitation from January 2005 through December 2007.

APPENDICES

Table A-1: Raw data of *Tamarix* density live stems m^{-2} in 2006. Means were calculated by quadrat (n=26, transects) and by transect (n=20, quadrats). Qudrats 1 and 2 correspond to site 1 ect.

	Transects												
Quadrat	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.25	0.25	0	0	0	0.75	0	0	4	0	0	6.25	0
3	0	0	0	0	0	0	0	0	3.25	0	0	2	0
4	0	0	0	0.25	0	0	0.25	1.50	4.25	0.25	0	3.50	0
5	0.25	0	0	0	0	0	0.25	0	1	0	4	7.50	0
6	0	0	0	0	0	0	0.50	0.25	1.50	0	7	12.50	0
7	0	0	0.25	0	2.75	0	4.25	0	1	0	3.75	6.50	0
8	0	0	0	0	7.50	0	7.50	0	0	0.25	4	6.75	0
9	0.25	0	0	0	9.25	0	5	0	0	0	2.50	1	0
10	0	0	0	0	8.25	0	0	1.50	0	0	0.75	2.50	0
11	0	0	0.25	0	12.25	0	6	1	0	0	0.25	0.25	0
12	0	0	0	0	7.25	0	0	0	1	5.75	0	0	0.25
13	0	0	0	0	7.50	0	0	0.75	3	4.50	0	0	2
14	0	0	0.25	0	8.25	0	0	1.25	6.50	3.25	0	0	0.75
15	0	0	0	0.50	10.75	0	0	0.25	9.25	6.25	1.25	0.25	1.25
16	0	0	0	0	4.25	0	0	1	16.25	10	3	7.50	0.25
17	0	0	0	0	2	0.25	12.5	0.25	17.50	5.25	10	5.75	1.50
18	0	0	0	0	0.75	0.75	12.5	0	15	6.25	6.50	5.25	2.50
19	0	0	0	0	1.50	0	25	0	13.75	2	3.25	6.25	2.25
20	0	0	0	0	1.25	0.25	18.75	0	15.75	8	0.75	6.75	0.75
Transect mean	0.03	0.01	0.03	0.03	4.17	0.10	4.62	0.38	5.65	2.58	2.35	4.02	0.57

Table A-1: continued

	Transects													
Quadrat	14	15	16	17	18	19	20	21	22	23	24	25	26	Quad Mean
1	0	0.25	0.25	0	0	0.25	0	0.75	5.75	0	0	0	0	0.28
2	0.75	0	0	0	0	0.50	0	0.50	1.25	0	0	0	0	0.56
3	2.50	0	0.25	0	0	6.25	0	0.75	0.5	0	0	0	0	0.60
4	3.25	0	0	0	0	0.50	0.50	1.50	0	0	0	0	0	0.61
5	2.25	0	0	0	0	1.75	0.75	6.75	0	0	0	0	0	0.94
6	2	0	0	0	0	0.75	0.50	12	0	0	0	0	0	1.42
7	2.75	0.25	0	0	0	0.25	0.25	20.75	0	0	0	0	0	1.64
8	1	0	0	0	0	0	0	23.50	0	0	0	0	0	1.94
9	0.25	0.25	0	0	0	1	1	20	0	0	0	0	0	1.56
10	0.25	0.50	0.25	0	0	2	7.50	1.50	0.25	0	0	0	0	0.97
11	0.25	0	0	0	0	7	12.5	0	4.25	0	0	0	0	1.69
12	3.25	0	0.50	0	0	5	3.25	0	11.50	0	0	0	0	1.45
13	3	0	1	0	0	0	4	0	9.75	0	0	0	0	1.37
14	2.50	0	0	0	0	3	1.75	0	14.5	0	0	0	0	1.62
15	3.25	1	0	0	0.25	1.50	6	0	3	0	0	0	0	1.72
16	3	1.25	0	0	1	5.75	1.75	0	0.50	0	0	0	0	2.13
17	2.75	0.25	0.25	1.50	0.75	3	0	0	0	0	0	0	0	2.44
18	5	1	0.25	1.25	3	0	0	0	0	0	0	0	0	2.31
19	4.25	0	0.25	0.25	4.75	5.25	0	8	0.25	0	0	0	0	2.96
20	3	0.25	0.50	1.25	5	6.50	0	15.75	0.50	12.75	10.50	0	0	4.16
Transect mean	2.26	0.25	0.17	0.21	0.73	2.51	1.98	5.58	2.60	0.63	0.52	0	0	

Table A-2: Raw data of *Tamarix* density live stems m^{-2} in 2007. Means were calculated by quadrat (n=26, transects) and by transect (n=20, quadrats).

	Transects											
Quadrat	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	5.75	0	0	0	0	0	0	5.50
2	0.25	0.25	0	0	10	0.25	0.25	0	0	0	0	1.75
3	0	0	0	0	17.50	0	0	0	0	0	0	0
4	0	0	0	0.25	10	0	0	0	0	0	2.50	0
5	0.25	0	0	0	5.25	0	0.25	0	0	0	6	0
6	0	0	0	0	6.25	0	0	0	0	0	1.25	0
7	0	0	0.25	0	4.25	0	0	0	0	0	2.75	0
8	0	0	0	0	5.75	0	0	0	0	0	2	0
9	0.25	0	0	0	6.50	0	0	0	0	0	0.50	2.50
10	0	0	0	0	4.75	0	0.50	0.50	0	0	1	10
11	0	0	0.25	0	3	0	0	0	0	0	0.75	4.25
12	0	0	0	0	8.50	0	0	0	0.75	0.50	0.50	5.50
13	0	0	0	0	5	0	1.50	1.50	0.75	3.75	0	7.50
14	0	0	0.25	0	1	0	0.25	0.25	1.50	0.75	0	0
15	0	0	0	0.25	0.50	0	1.50	1.50	3.25	0.50	0	3.75
16	0	0	0	0	0.50	0	0	0	4.25	0	0	4.25
17	0	0	0	0	1	0	0.25	0.25	5.75	1	2.25	3
18	0	0	0	0	0.25	0	0	0	2.50	0.50	7.50	0
19	0	0	0	0.25	0.75	0	0	0	2.50	0.25	3.50	0
20	0	0	0	0.25	0.25	0	0	0	5	2	0.50	0
Transect mean	0.03	0.01	0.03	0.05	4.83	0.01	0.22	0.20	1.31	0.46	1.55	2.40

Table A-2: continued

	Transects													
Quadrat	14	15	16	17	18	19	20	21	22	23	24	25	26	Quad Mean
1	0	0	0.25	0	0	1	0	0.75	0.25	0	0	0	0	0.58
2	0	0	0	0	0	2.25	0	0.25	0.25	0	0	0	0	0.65
3	0	0	0	0	0	0.25	0	0.50	0	0	0	0	0	0.82
4	0	0	0	0	0	1.25	0.50	3	0	0	0	0	0	0.73
5	0	0	0	0	0	0.25	1	1.25	0.50	0	0	0	0	0.57
6	0	0	0	0	0	5.75	1	0.50	12.50	0	0	0	0	1.08
7	0	0.50	0	0	0	1	0.25	6.75	1.25	0	0	0	0	0.66
8	0	0.50	0	0	0	1.50	0.25	10	1	0	0	0	0	0.83
9	0	0.75	0	0	0	0.25	1.50	5.75	9	0	0	0	0	1.06
10	0	0.75	0	0	0	0	4.25	6	7	0	0	0	0	1.34
11	0	0	0	0	0	0.25	8.25	0	0.25	0	0	0	0	0.67
12	0.50	0	1.50	0	0	1.50	2.75	0	0	0	0	0	0	0.88
13	1.75	0.25	0.50	0	0	5	0.75	1	0	0	0	0	0	1.22
14	2	0.25	0	0	0.50	5.50	0.75	0	0	0	0	0	0	0.62
15	1	1	0	0	0	3.25	0	0	0	0	0	0	0	0.73
16	0.50	0.50	0.25	1	0.25	0.25	0	0	0	0	0	0	0	0.52
17	2.50	0	0.25	0.75	0.50	0	0	0	0	0	0	0	0	0.79
18	2	0.25	0	1.5	2	1.50	0	0	0	0	0	0	0	0.78
19	1.25	0.50	0	0	2.75	1.25	0	0	0	0	1.75	0	0	0.65
20	0	0.50	0	0.25	1	0	0	0	0.75	0.75	0.50	0	0	0.47
Transect mean	0.57	0.28	0.13	0.17	0.35	1.60	1.06	1.78	1.63	0.03	0.11	0	0	

Table A-3: Raw data of soil salinity EC (mmhos/cm) in 2006 by site. Values are from a single composite analysis of 5 pooled sample cores (Carter 1993) spanning each transect in 2006.

	Sites												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Mean EC	54.9	106.5	27.7	54.2	32.7	18.8	58.3	73.5	114.9	44.4	48.5	166.2	222.3

Table A-4: Raw data of *Tamarix* density live stems m $^{-2}$ in 2007.Values are for single analyses of 5 pooled cores within each samples quadrat.

	Transects											
Qudrat	1	2	3	4	5	6	7	8	9	10	11	12
1	12.2	10.8	7.5	18.7	1.3	0.2	0.8	15.8	0.2	11.8	6.1	4.6
3	3.7	0.2	5.1	14.4	0.1	0.3	0.1	2.8	1.0	18.8	2.1	2.7
8	0.5	0.2	0.9	0.7	0.2	0.2	0.2	0.2	7.5	0.6	7.0	4.1
13	0.5	1.4	18.9	0.2	0.2	0.1	0.3	0.3	1.6	0.2	1.6	3.2
18	3.6	4.5	5.4	1.2	0.4	0.2	0.4	0.2	0.6	0.1	1.2	2.0
Mean EC	4.1	3.4	7.5	7.0	0.4	0.2	0.3	3.8	2.2	6.3	3.6	3.3

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	Transects														
Qudrat	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Quad. Mean
1	2.0	8.4	4.8	2.9	29.7	23.3	2.9	16.8	29.9	16.9	31.0	30.8	35.5	30.1	13.6
3	1.3	3.3	2.2	1.1	15.8	8.6	16.3	10.9	6.2	0.7	14.5	25.3	28.7	23.3	8.1
8	1.0	1.3	3.2	1.3	16.4	14.3	0.8	7.5	6.4	19.5	24.3	27.0	28.0	24.9	7.6
13	0.8	4.9	3.8	2.4	18.7	18.3	1.2	10.4	5.9	8.2	17.4	19.8	31.9	29.6	7.8
18	1.9	1.8	4.3	3.4	24.1	6.5	8.0	6.2	6.2	14.4	0.9	1.1	35.5	20.1	5.9
Transect Mean	1.4	3.9	3.7	2.2	21.0	11.9	5.8	10.3	10.9	11.9	17.6	20.8	31.9	25.6	

Table A- 5: Correlation matrix of soil vs. biological variables * $p < 0.05$; ** $p < 0.01$; all others not significant.

Biological variables	*Tamarix* 2007 Density	*Tamarix* 2007 Height	*Tamarix* 2007 % cover	*Distichlis* 20007 % cover	*Eragrostis* 20007 % cover
Soil variables					
EC	-0.213*	-0.172	-0.305**	-0.277**	-0.313**
pH	0.017	-0.149	0.067	0.151	0.045
OM	0.147	0.354**	0.042	0.329**	-0.198*
SS	-0.036	0.017	0.087	0.218*	0.296**
P	0.062	0.362**	0.017	0.201*	0.276**
Ca	-0.006	-0.007	-0.020	0.164	0.002
Mg^{2+}	-0.154	0.219*	-0.028	0.066	-0.376**
K	-0.140	0.362**	0.072	0.190*	-0.192*
Na^{+}	-0.195*	-0.114	-0.256**	-0.243**	-0.290**
B	0.041	0.226*	0.030	0.164	0.168
Fe	0.038	0.231*	0.099	0.066	0.262**
Mn	0.093	0.330**	0.130	0.244**	-0.247**
Cu	0.081	0.341**	0.141	0.183*	0.181*
Zn	-0.126	0.179*	0.060	0.081	0.041
Al	0.117	0.268**	0.099	0.253**	-0.067
NO_3^{-}-N	-0.034	0.296**	0.111	0.338**	0.063
NH_4^{+}	0.124	0.276**	0.092	0.137	-0.002

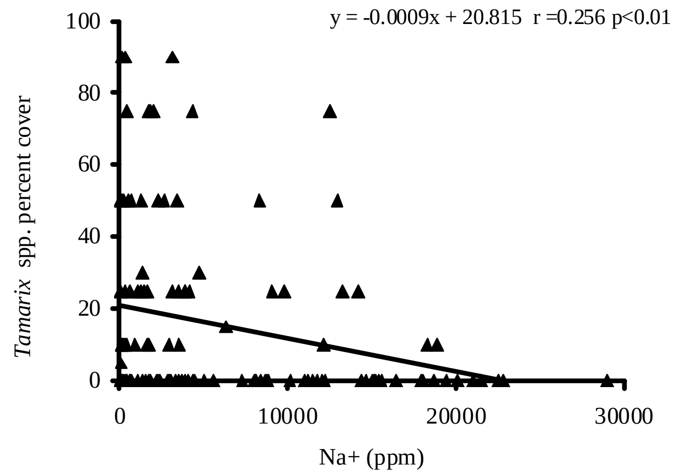
Table A-6: Correlation matrix of soil vs. soil variables* $p < 0.05$;
** $p < 0.01$; all others not significant.

Soil variables	EC	pH	OM	SS	P	Ca	Mg^{2+}	K	Na^{+}
EC	1	0.109	0.036	0.720**	0.048	0.078	0.509**	0.174*	0.922**
pH		1	0.322**	0.160	0.197*	0.168	0.182*	0.325**	0.164
OM			1	0.099	0.796**	0.149	0.636**	0.873**	0.065
SS				1	0.344**	0.177*	0.665**	0.348**	0.808**
P					1	0.083	0.813**	0.800**	0.253**
Ca						1	0.167	0.229**	0.101
Mg^{2+}							1	0.724**	0.652**
K								1	0.311**
Na^{+}									1
B									
Fe									
Mn									
Cu									
Zn									
Al									
NO_3^--N									
NH_4^+-N									

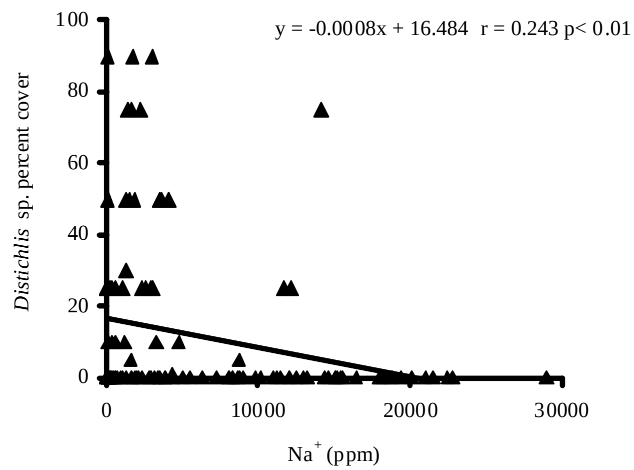
Table A-6: continued

Soil variables	B	Fe	Mn	Cu	Zn	Al	NO_3^--N	NH_4^+-N
EC	0.284**	0.32**	0.031	0.057	0.184*	0.257**	-0.370**	-0.284**
pH	0.300**	0.195*	0.269**	0.248**	0.438**	0.222**	0.270**	0.176*
OM	0.737**	0.374**	0.825**	0.745**	0.491**	0.699**	0.668**	0.149
SS	0.488**	0.726**	0.294**	0.322**	0.043	-0.157	-0.353**	0.03
P	0.691**	0.616**	0.881**	0.769**	0.396**	0.574**	0.385**	0.188*
Ca	0.476**	0.093	0.154	0.259**	0.064	0.106	0.115	0.219*
Mg^{2+}	0.754**	0.654**	0.734**	0.636**	0.243**	0.320**	0.118	0.479**
K	0.785**	0.599**	0.829**	0.865**	0.428**	-.615**	0.462**	0.270**
Na^+	0.404**	0.518**	0.189*	0.236**	-0.081	-0.131	-0.345**	-0.202*
B	1	0.571**	0.732**	0.721**	0.765**	0.397**	0.404**	0.132
Fe		1	0.614**	0.661**	0.177*	0.194*	-0.118	0.391**
Mn			1	0.785**	0.483**	0.585**	0.381**	0.196*
Cu				1	0.476**	0.607**	0.372**	0.360**
Zn					1	0.559**	0.469**	0.242**
Al						1	0.538**	0.148
NO_3^--N							1	0.094
NH_4^+-N								1

(a)



(b)



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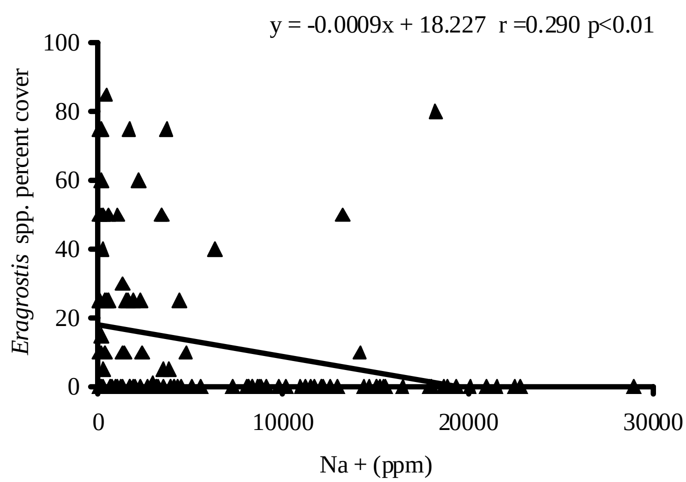
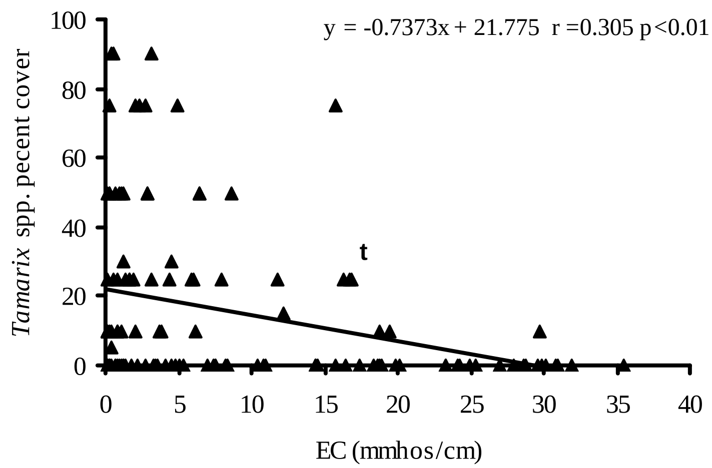


Figure A-1:Relationship between Na^+ and (a) *Tamarix* spp. (b) *Distichlis* sp. and (c) *Eragrostis* spp.

(a)



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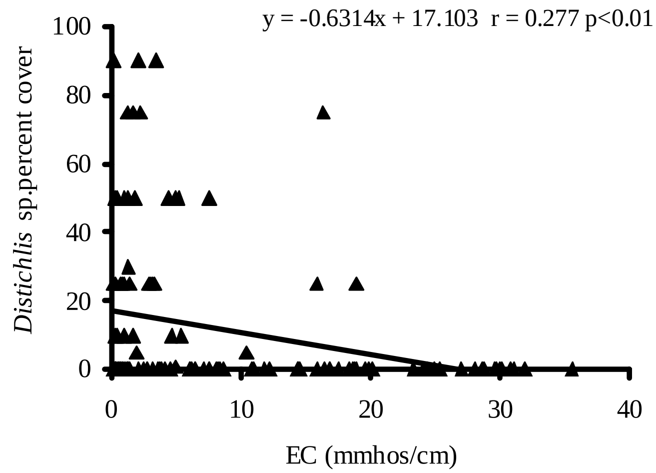

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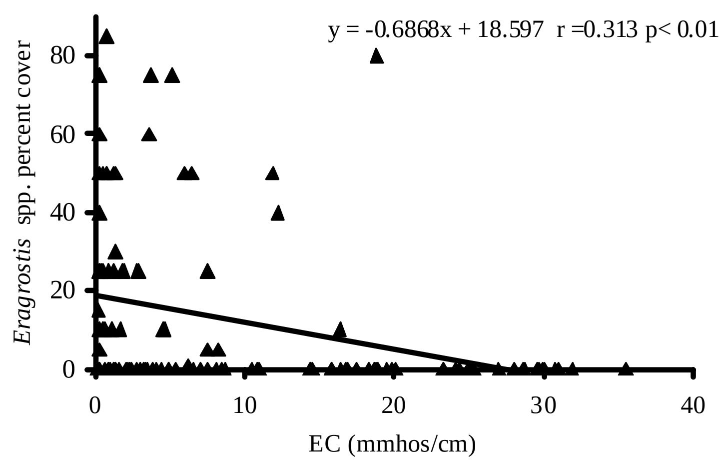


Figure A-2: Relationship between EC and (a) *Tamarix* spp. (b) *Distichlis* sp. and (c) *Eragrostis* spp.

(a)

(b)

(c)

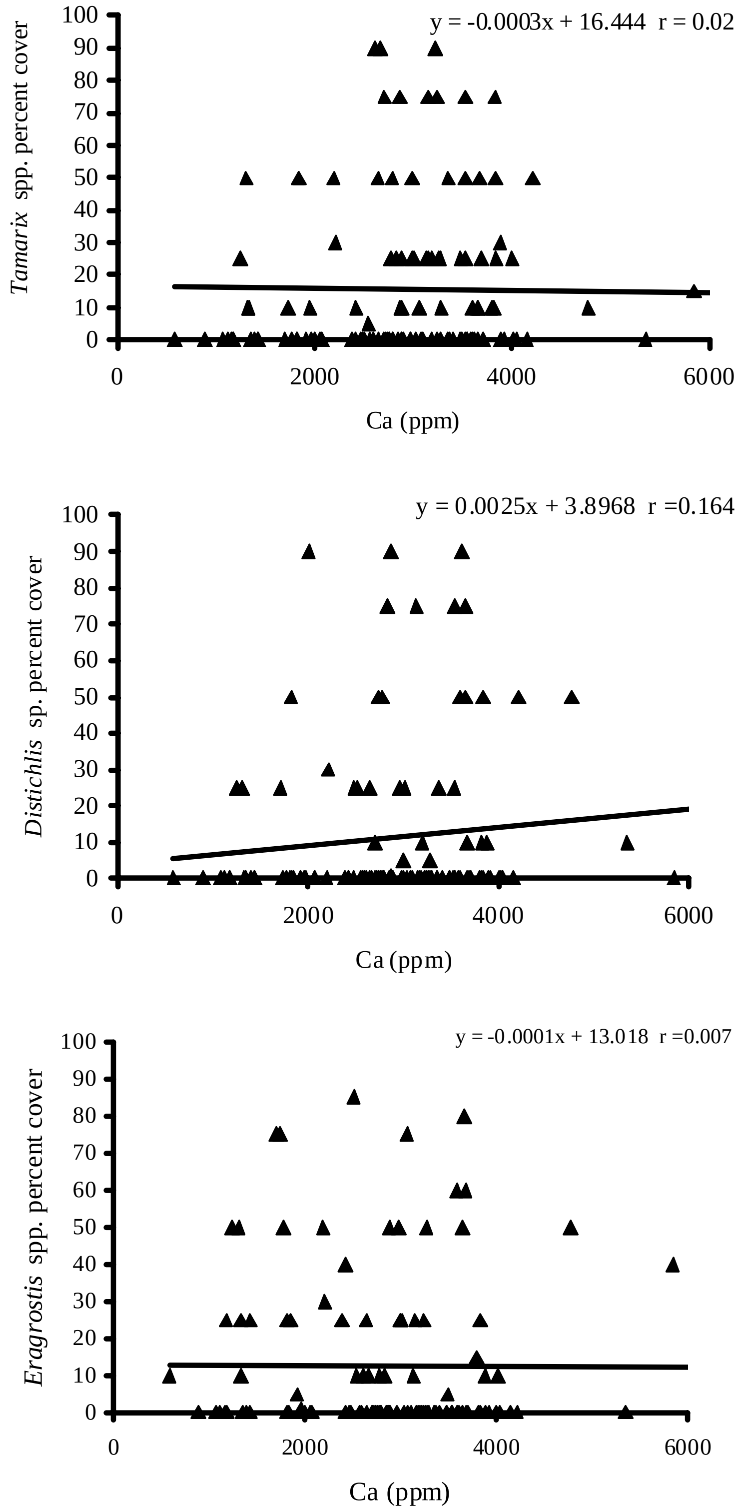
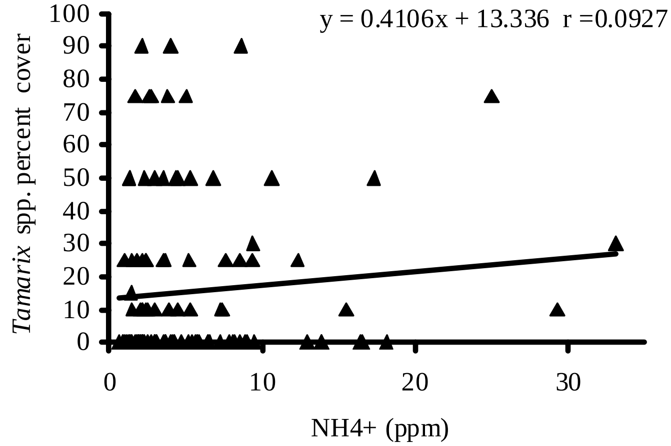


Figure A-3: Relationship between Ca and (a) *Tamarix* spp. (b) *Distichlis* sp. and (c) *Eragrostis* spp.

(a)



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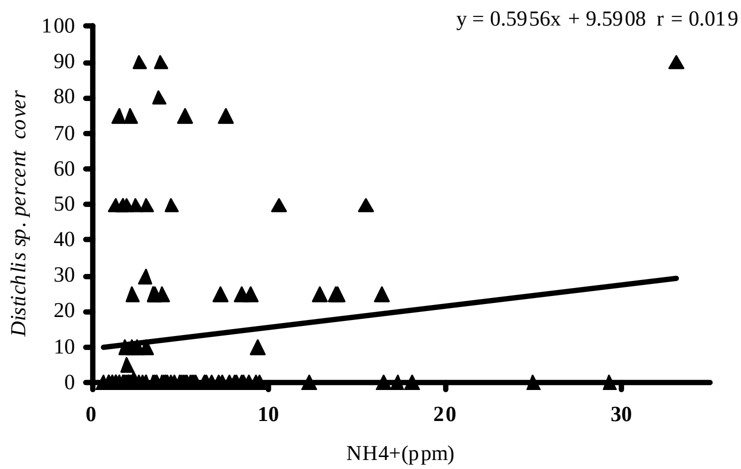


(c)

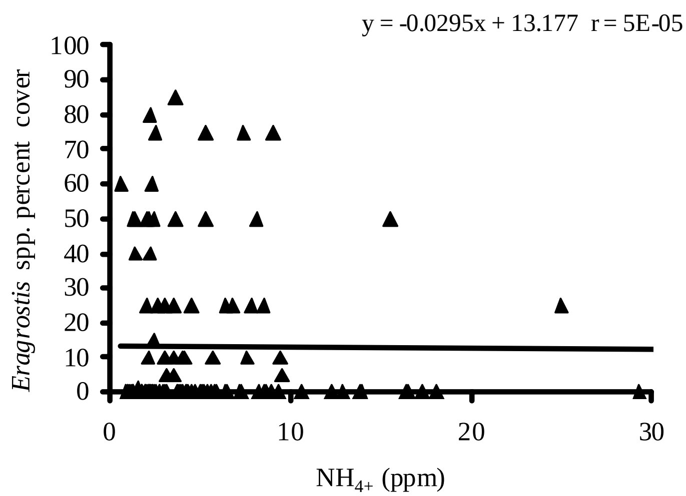
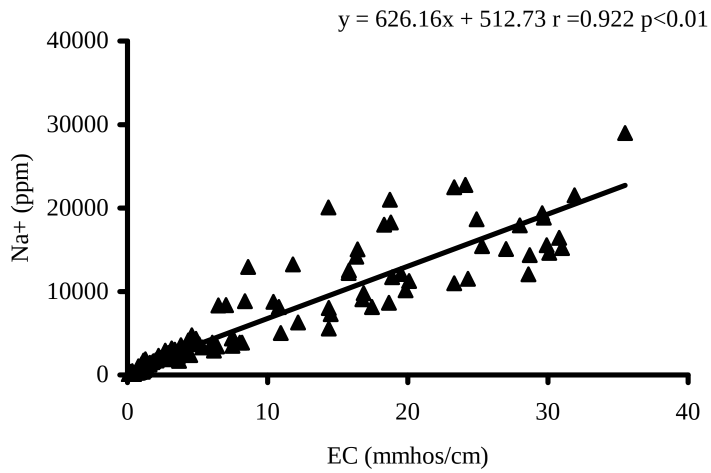


Figure A-4: Relationship between NH_4^+ and (a) *Tamarix* spp. (b) *Distichlis* sp. and (c) *Eragrostis* spp.

(a)



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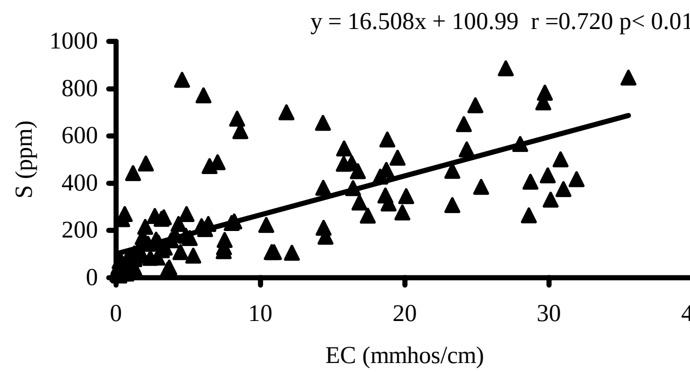

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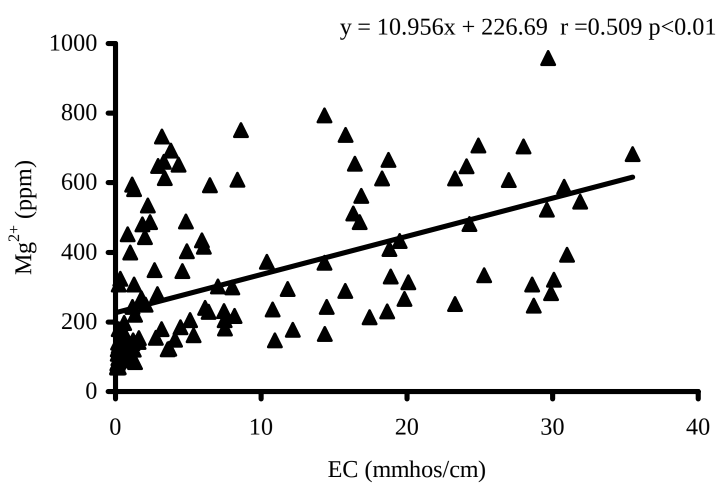

Figure A-5: Relationship between EC and (a) Na^+ (b) S and (c) Mg^{2+}.

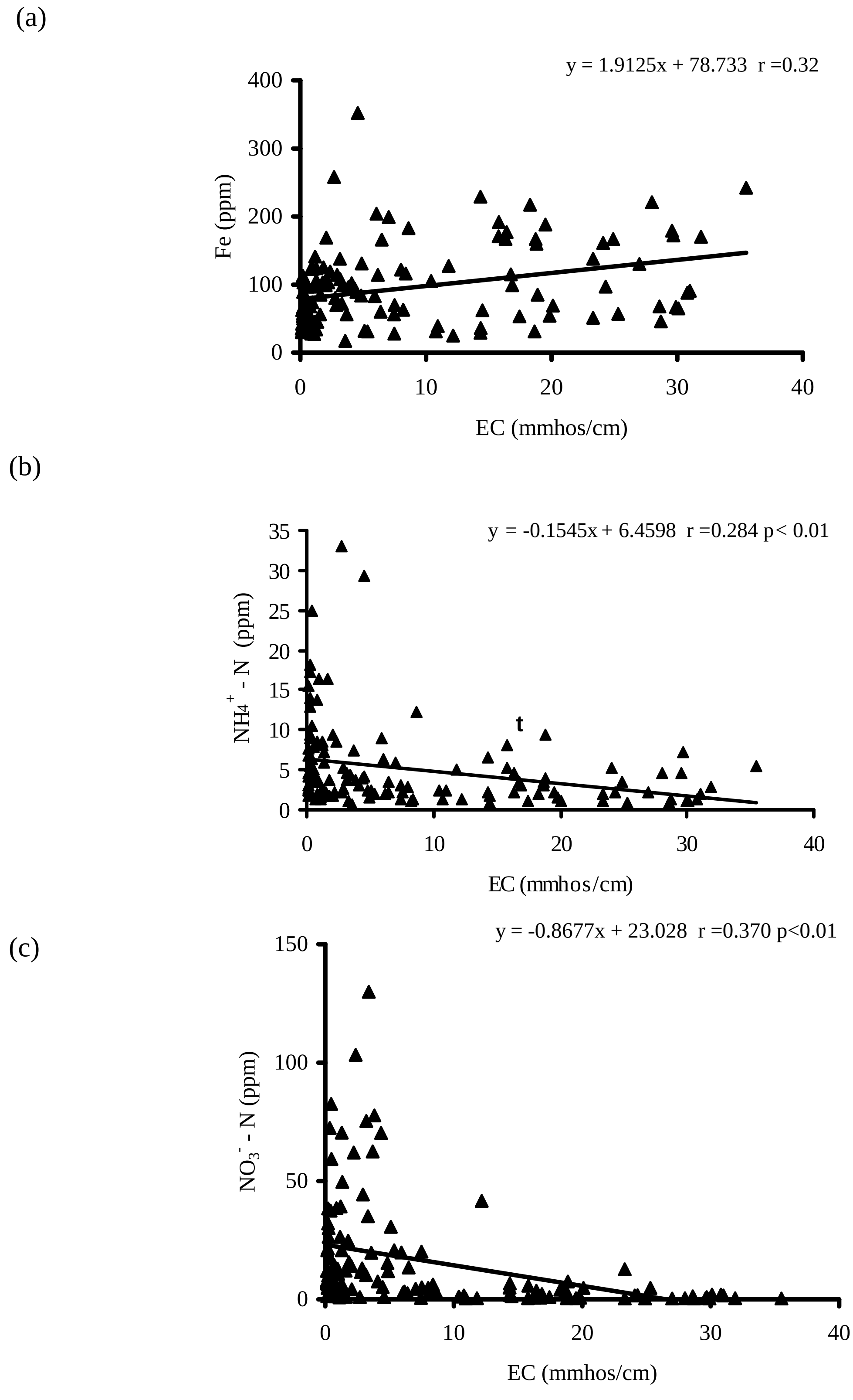

Figure A-5: Relationship between EC and (a) Fe (b) NH_4^+-N and (c) NO_3^--N.

VITA

Karen Louise Ray

Candidate for the Degree of

Master of Science

Thesis: *TAMARIX* SPECIES (SALT CEDAR) STEM DENSITY ALONG FLUVIAL AND SALINTY GRADIENTS ON THE SALT PLAINS NATIONAL WILDLIFE REFUGE

Major Field: Botany

Biographical:

Personal Data: Born in Enid, Oklahoma, USA on 8th December 1957

Education: Received Associates of Science degree in Industrial Laboratory Technology from Oklahoma State University OKC, Oklahoma City, Oklahoma in May 2000. Received Geographical Information System certificate from Oklahoma State University, Stillwater, Oklahoma in December 2009. Received Bachelor of Science degree in Botany from Oklahoma State University, Stillwater, Oklahoma in May 2003;Completed the requirements for the Master of Science in Botany at Oklahoma State University, Stillwater, Oklahoma in May 2010.

Experience: Food Laboratory Technician 1998-2000. Research Assistant; Vegetation and soil sampling in the Salt Plains National Wildlife Refuge, spring and summer 2004, 2006, & 2007. Teaching Assistant; Introduction to Plant Biology 2003-2008

Professional Memberships: Golden Key International Honor Society, Oklahoma Academy of Sciences, Oklahoma State University Botanical Society.

Name: Karen Louise Ray Date of Degree: May, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: *Tamarix* species (Salt Cedar) Stem Density Along Fluvial and Salinity Gradients on the Salt Plains National Wildlife Refuge

Pages in Study: 54 Candidate for the Degree of Master of Science

Major Field: Botany

Scope and Method of Study: The purpose of this study was to examine *Tamarix* density patterns along stream and salinity gradients on the Salt Plains National Wildlife Refuge. I established 26 transects perpendicular to the barren salt flats and the nearest creek. Each transect contained 20 4^2m quadrats (sampling unit). In each quadrat I identified and determined percent cover of all vascular plant species. Density, diameter, and height of only *Tamarix* species were recorded. In 5 quadrats of each transect soil samples were collected and analyzed for EC (electrical conductivity). I tested all variables for significant correlations using bivariate Pearson two-tailed correlation. Significant correlations were then tested using regression analysis.

Findings and Conclusions: *Tamarix* stem density decreased while species richness increased during the two-year study period. *Tamarix* stem density was affected by increased flooding due to increased precipitation in 2007. *Tamarix* species < 2m in height were removed by the affects of the 2007 peak flows through scouring or burial under sediment. The removal of *Tamarix* reduced competition pressure allowing other vascular plant species to increase.

Advisor's Approval: William J. Henley